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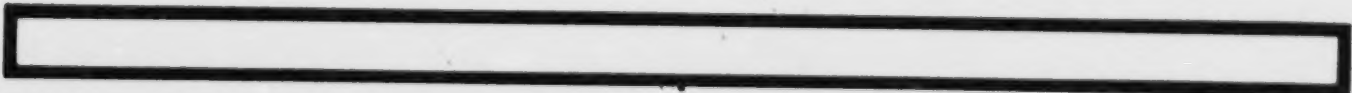
Technology Evaluation Report
SITE (Superfund Innovative Technology Evaluation)
Program Demonstration Test. Terra Vac in situ
Vacuum Extraction System, Groveland, Massachusetts. Volume 1

Foster Wheeler Enviresponse, Inc., Livingston, NJ

Prepared for:

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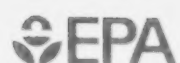
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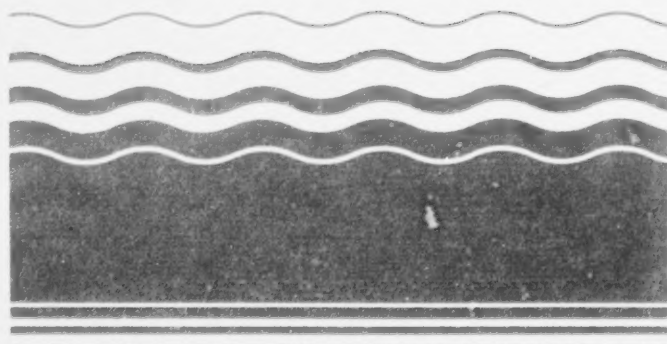


Technology Evaluation Report:

SITE Program
Demonstration Test
Terra Vac In Situ Vacuum
Extraction System
Groveland, Massachusetts

Volume I

SITE
*SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION*



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April 1989

Technology Evaluation Report:
SITE Program Demonstration Test
Terra Vac In Situ Vacuum Extraction System
Groveland, Massachusetts

Volume I

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

NOTICE

The information in this document has been funded by the U.S. Environmental Protection Agency under Contract No. 68-03-3255 and the Superfund Innovative Technology Evaluation (SITE) Program. It has been subjected to the Agency's peer review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

FOREWORD

The Superfund Innovative Technology Evaluation (SITE) program was authorized in the 1986 Superfund amendments. The program is a joint effort between EPA's Office of Research and Development and the Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous waste treatment technologies necessary to implement new cleanup standards which require greater reliance on permanent remedies. This is accomplished through technology demonstrations which are designed to provide engineering and cost data on selected technologies.

This project was a demonstration of Terra Vac Inc.'s in situ vacuum extraction process on the property of an operating machine shop. The property is part of the Groveland Wells Superfund Site in Groveland, Massachusetts. Information on the performance and cost of the process was obtained as the result of extensive field observations, data collection, and sampling and analytical work. This information may be employed in assessments at other sites. The documentation of the demonstration will consist of two reports. This Technology Evaluation Report describes the field activities and laboratory results. An Applications Analysis Report will follow and provide an interpretation of the data and conclusions on the applicability of the technology.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Building, Springfield, VA, 22161, (702) 487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at 1-800-424-9346 or 382-3000 in Washington, DC to inquire about the availability of other reports.

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ABSTRACT

An evaluation was made of the performance of Terra Vac Inc.'s vacuum extraction system during a 56-day demonstration test run at Valley Manufactured Product Company's site in Groveland, Massachusetts. This site is part of the Groveland Wells Superfund site, a source of drinking water for the town of Groveland, and is contaminated mainly by trichloroethylene.

The report includes a detailed discussion of the operations of the vacuum extraction unit, a process description and diagram of the system, and a summary of the sampling and analytical protocols. The final sampling and analytical report prepared by the sampling and analytical contractor, including the quality assurance project plan, is an integral part of this document. An overall cost evaluation of the process is included and conclusions are drawn regarding the efficiency of the process and its applications to other Superfund sites across the country.

Results of the demonstration test are promising, and it is felt that a site remediation can be accomplished using this technology. Both shallow soil gas and soil VOC concentrations were reduced substantially and wellhead VOC gas concentrations showed a decline with time, which was correlatable. The process worked well in soils of both high and low permeability.

The system operation was very reliable during the 56-day demonstration test run, and the only operation attention required was to replace the spent activated carbon canisters with fresh canisters.

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* Volume II contains the Sampling and Analytical Report including a Quality Assurance section and eight appendices, with tables of soil boring analyses, soil gas analyses, wellhead gas analyses, physical properties of soil strata, and analytical SOPs.

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ABBREVIATIONS AND SYMBOLS

API	American Petroleum Institute
ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm/sec	centimeters per second
cu ft	cubic feet
cu yd	cubic yard
DCE	trans 1,2-dichloroethylene
ECD	electron capture detector
EPA	Environmental Protection Agency
EW	extraction well
FID	Flame ionization detector
GC/MS	Gas Chromatograph/Mass Spectrometer
g/ml	grams per milliliter
gmol	gram mole
GPM	gallons per minute
in Hg	inches of mercury
KPa	kilopascal
Kw	kilowatt
m/sec	meters per second
MeCl	methylene chloride
mg/kg	milligrams per kilogram
mg/l	milligrams per liter
MW	monitoring well
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List

ABBREVIATIONS AND SYMBOLS (cont.)

OLM	Organic Leachate Model
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
PAHs	Polycyclic Aromatic Hydrocarbons
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
ppmw	parts per million by weight
psi	pounds per square inch
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RREL	Risk Reduction Engineering Laboratory
SARA	Superfund Amendments and Reauthorization Act of 1986
SCFM	standard cubic feet per minute
SITE	Superfund Innovative Technology Evaluation Program
TCE	trichloroethylene
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total Organic Carbon
TRI	1,1,1-trichloroethane
u	micron
ug/l	micrograms per liter
VOC	volatile Organic Compound
VHS	Vertical and Horizontal Spread Model

CONVERSIONS

	English (US)	Metric (SI)
Area:	1 ft ²	9.2903 x 10 ⁻³ m ²
	1 in ²	6.4516 cm ²
Flow Rate:	1 gal/min	6.3090 x 10 ⁻⁵ m ³ /s
	1 gal/min	6.3090 x 10 ⁻² L/s
	1 Mgal/d	43.8126 L/s
	1 Mgal/d	3.7854 x 10 ³ m ³ /d
	1 Mgal/d	4.3813 x 10 ⁻² m ³ /s
Length:	1 ft	0.3048 m
	1 in	2.54 cm
	1 yd	0.9144 m
Mass:	1 lb	4.5359 x 10 ⁻² g
	1 lb	0.4536 kg
Volume:	1 ft ³	28.3168 L
	1 ft ³	2.8317 x 10 ⁻² m ³
	1 gal	3.7854 L
	1 gal	3.7854 x 10 ⁻³ m ³

ft = foot, ft² = square foot, ft³ = cubic foot

in = inch, in² = square inch

yd = yard

lb = pound

gal = gallon

gal/min = gallons per minute

Mgal/d = million gallons per day

m = meter, m² = square meter, m³ = cubic meter

cm = centimeter, cm² = square centimeter

L = liter

g = gram

kg = kilogram

m³/s = cubic meters per second

L/s = liters/sec

m³/d = cubic meters per day

ACKNOWLEDGMENTS

This report was prepared under the direction and coordination of Mary Stinson, EPA SITE Program Manager in the Risk Reduction Engineering Laboratory - Cincinnati, Ohio. Contributors and reviewers for this report were Mr. James Ciriello of EPA Region I - Remedial Project Manager for the Groveland Superfund site; John Kingscott from the Office of Solid Waste and Emergency Response; Greg Ondich from the Office of Research and Development; James Malot and Neil James from Terra Vac Corporation; and Patrick Ford and James Thomas from Alliance Technologies, Inc.

This report was prepared for EPA's Superfund Innovative Technology Evaluation (SITE) Program by Peter A. Michaels of Foster Wheeler Enviresponse, Inc. for the U.S. Environmental Protection Agency under Contract No. 68-03-3255.

SECTION 1

INTRODUCTION

Environmental regulations enacted in 1984 (and recent amendments to the Superfund program) discourage the continued use of landfilling of wastes in favor of remedial methods that will treat or destroy the wastes. The Superfund program now requires that, to the maximum extent practicable, cleanups at Superfund sites must employ permanent solutions to the waste problem.

The Superfund Innovative Technology Evaluation (SITE) program is one major response to the challenge of finding safe ways to deal with waste sites. Part of the program includes carefully planned demonstration projects at certain Superfund sites to test new waste treatment technologies. These new alternative technologies are ones which will destroy, stabilize, or treat hazardous wastes by changing their chemical, biological, or physical characteristics.

Under the SITE program, which is sponsored jointly by the Office of Research and Development (ORD) and the Office of Solid Waste and Emergency Response (OSWER), the USEPA selects 10 or 12 Superfund sites each year at which pilot studies of promising technologies can be conducted. Sites are chosen to match the effectiveness and applicability of a particular technology with specific waste types and local conditions. The pilot studies are carefully monitored by the USEPA. Monitoring and data collection determines how effectively the technology treats the waste, how cost-effectively the technology compares with more traditional approaches, and that the operation can be conducted within all public health and environmental guidelines.

The Groveland Wells site was selected for such a demonstration project for 1987. The site is the location of a machine shop, the Valley Manufactured Products Company, Inc., which employs approximately 25 people and manufactures, among other things, parts for valves. The company has been in business at the site since 1964. As an integral part of its building-wide operation of screw machines, the company has used different types of cutting oils and degreasing solvents, mainly trichloroethylene, tetrachloroethylene, trans-1,2-dichloroethylene, and methylene chloride.

The contamination beneath the shop apparently is caused by a leaking storage tank and by former improper practices in the storage and handling of waste oils and solvents. The contamination plume is moving in a northeasterly direction towards and into the Mill Pond.

The USEPA has been involved since 1983, when the Groveland Wells site was finalized on the National Priorities List. The initial Remedial Investigation (RI) of the Valley property was carried out by the responsible party (RP), Valley Manufactured Products Company, Inc. A supplemental RI was conducted by Valley in the Fall/Winter of 1987 to determine more completely the full

nature of contamination at the Valley site. A source control Feasibility Study was performed by USEPA to evaluate various methods for cleaning up or controlling the remaining contaminants. A Record of Decision (ROD) for the site was signed in October 1988 calling for vacuum extraction and groundwater stripping.

The Terra Vac system is being utilized in many locations across the nation. This system was first demonstrated at a Superfund site in Puerto Rico, the Upjohn facility in Barceloneta, where carbon tetrachloride had leaked from an underground storage tank. The first aquifer was the sole source of drinking water three hundred feet below. Although groundwater contamination occurred rapidly, most of the pollutant was in the soil. Since this cleanup began, soil contamination purportedly has been reduced to nondetectable limits.

This report is based on monitoring the Terra Vac patented vacuum extraction process (U.S. Patent Nos. 4593760 and 4660639) at the Groveland Wells site during a four-and-one-half month field operation period, with emphasis on a 56-day demonstration test active treatment period. The report interprets results of analyses performed on samples and establishes reliable cost and performance data in order to evaluate the technology's applicability to other sites.

SECTION 2

EXECUTIVE SUMMARY

The SITE program demonstration test of the Terra Vac in situ vacuum extraction process was conducted at the Valley Manufactured Products Company, Inc. property, which is a part of the Groveland Wells Superfund site, in Groveland, MA. The vacuum extraction process is a technique for the removal of volatile organic compounds (VOCs) from the vadose zone or unsaturated zone of soils. Various estimates by EPA Region I and the Massachusetts Department of Environmental Quality Engineering (DEQE) have placed the total amount of contamination at the Valley site at between 3,000 and 30,000 lb of volatile organic compounds (VOC).

This SITE program demonstration test was designed to focus on the periphery of the main zone of contamination. A triangular configuration of three barrier extraction wells and one main extraction well was set up with these test objectives in mind:

- o to determine the ability of the technology to remove VOCs from the vadose zone
- o to assess the effectiveness of the technology in various soil types
- o to correlate declining recovery rates with time
- o to correlate VOC concentrations in soils with those in extracted vapors

The SITE test program at Valley Manufactured Products Company was conducted from December 1, 1987 to April 26, 1988, when the last soil borings were taken. During the time that Terra Vac was operating their system, EPA SITE program and Region I staff along with contractors Enviroresponse, Inc. and Alliance Technologies Corporation were present to observe and record data on the operation of the technology and to conduct sampling and analytical work. QA/QC audit teams from S-Cubed, an RREL contractor, validated the test protocols in both the on-site mobile laboratory for the wellhead gas analyses, and in the main laboratory in Bedford, MA for the soil boring analyses.

The final Quality Assurance/Quality Control procedures, as prepared by Alliance Technologies Corporation, appear in Section 4 of Volume II.

Summary of Results

Presented below is a summary of the results relating to each of the above defined objectives of the test program.

- o VOC removal from the vadose zone.

The results of flow measurements of process stream vapors along with concentration levels in the wellhead vapors analyzed indicate that a total of 1,297 lb of VOCs were extracted during a 56-day vacuum unit operating period. These results were confirmed by analysis of the activated carbon emission control canisters employed on this project.

Analysis of the contents of these canisters indicated a total of 1,353 lb of VOCs recovered.

Shallow soil gas concentrations, in the vicinity of the extraction wells were reduced by more than 95% during the course of the 56-day demonstration.

Soil VOC concentrations were also reduced. The greatest reduction came at EW4, which showed a better than 95% reduction in soil VOC levels. The majority of the soil borings in the vicinity of EW4 showed VOC removals to non-detectable levels. In the vicinity of the other three wells, the reduction of VOC in soil ranged from 9% to 30%. These three wells acted as barrier wells to EW4. EW1 was designed to show the highest reduction in VOC level, but was prevented from doing so by the migration of contaminants from the unexpectedly high levels around MW3.

o Effectiveness in various soil types

The vacuum extraction system was able to reduce substantially the concentration of VOCs in the area of MW3, which was described during the pretreatment drilling period as wet clay. Concentrations were reduced in this clay area by two orders of magnitude and more during the test period. From the limited data base, the permeability of a soil may not be a factor to consider in the application of this technology. It appears that a more important soil property to consider is porosity.

o Correlation of declining recovery rates

The process of vacuum extraction is an unsteady state process and should correlate well when the data is plotted on semi-log paper. This has been found to be the case with the data collected on this project. Plotting the logarithm of concentration versus time gives the best correlation coefficients.

o Prediction of time required for site remediation

Given the nonhomogeneous nature of the subsurface contamination, it was not possible to obtain a good correlation between VOC concentrations in wellhead gas and soil in order to predict site remediation times. Two wells, EW1D and EW2D, showed similar ratios of concentrations in soil ppmw to concentrations in wellhead gas ppmv. Predictions of soil concentrations based on Henry's Law are for the most part lower by an order of magnitude.

A rough estimation of the remediation time can be made by taking the ratio of soil to wellhead gas concentration and applying this ratio to solve for a wellhead gas concentration at a determined allowable soil concentration. The allowable soil concentration may be calculated by use of the Vertical and Horizontal Spread Model in conjunction with the Organic Leachate Model and applying an appropriate factor of safety depending upon the particular contaminant involved. For this particular site using an allowable soil concentration one order of magnitude lower than the calculated value might be appropriate since the contaminant involved is TCE and the Maximum Contaminant Level Goal (MCLG) for TCE is zero. Using this reasoning, an allowable soil concentration of 50 ppbw may be used for this site, which corresponds to an

approximate wellhead gas concentration of 8.9 ppb for EWIS. The equation correlating wellhead gas concentration with time is then solved to give 200 days' running time.

After 200 days the vacuum extraction system can be run intermittently to see if significant increases in gas concentrations occur upon restarting, after at least a two day stoppage. If there are no appreciable increases in gas concentration, the system may be stopped and soil borings taken and analyzed.

SECTION 3

PROCESS DESCRIPTION

3.1 INTRODUCTION

The vacuum extraction process is a technique for the removal of volatile organic compounds (VOCs) from the vadose or unsaturated zone of soils. Once a contaminated area is completely defined, an extraction well or wells, depending upon the extent of contamination, will be installed. A vacuum system induces air flow through the soil, stripping, and volatilizing the VOCs from the soil matrix into the air stream. The effect of increasing the vacuum extraction is to enhance the volatilization of the VOCs by increasing their partial pressure in the air stream. Liquid water is generally extracted as well along with the contamination. The two phase flow of contaminated air and water flows to a vapor liquid separator where contaminated water is removed. The contaminated air stream then flows through activated carbon canisters arranged in a parallel-series fashion. Primary or main adsorbing canisters are followed by a secondary or backup adsorber in order to insure that no contamination reaches the atmosphere. Table 3.1 presents the required equipment for the site, Figure 3.1 illustrates the layout of wells and equipment, and Figure 3.2 shows a schematic diagram of an extraction well.

Four extraction wells (EW1-EW4) and four monitoring wells (MW1-MW4) were drilled south of the shop. Each well was installed in two sections, one section to just above the clay lens and one section to just above the water table. The extraction wells were screened above the clay and below the clay. As shown in Figure 3.2, the well section below the clay lens was isolated from the section above by a bentonite portland cement grout seal. Each section operated independently of the other. The wells were arranged in a triangular configuration, with three wells on the base of the triangle (EW2, EW3, EW4) and one well at the apex (EW1). The three wells on the base were called barrier wells. Their purpose was to intercept contamination, from underneath the building and to the side of the demonstration area, before this contamination reached the main extraction well (EW1). It was the area enclosed by the four extraction wells that defined the area to be cleaned.

3.2 SITE CHARACTERISTICS

Geophysical investigations at the location of the demonstration project indicate that a northerly to easterly sloping bedrock surface exists approximately 40 to 50 ft below the higher elevations of the site. (See Figure 3.3.) The groundwater table generally follows the bedrock trends at varying depths depending on the season and slopes gently towards Mill Pond, some 400 ft northeast of the northern edge of the Valley Manufactured Products Co., Inc. building. The test area was located at the southeasterly portion of the Valley site, with the extraction and monitoring wells installed outside and adjacent to the building. The vapor-liquid separator, activated carbon canisters, and vacuum pump skid were located inside the building.

The subsurface profile in the test area consisted of medium sand and gravel just below the surface, underlain by finer sands and silty sands, a clay layer 3 to 7 ft in depth, and below the clay layer, coarser sands with gravel.

TABLE 3.1 EQUIPMENT LIST

Equipment	Number Required	Description
Extraction wells	4 (2 sections each)	2" SCH 40 PVC 24' total depth
Monitoring wells	4 (2 sections each)	2" SCH 40 PVC 24' total depth
Vapor-liquid separator	1	1000-gal capacity, steel
Activated carbon canisters	Primary: 2 units in parallel Secondary: 1 unit	Canisters with 1200 lb of carbon in each canister - 304 SS 4" inlet and outlet nozzles
Vacuum unit	1	Terra Vac Recovery Unit-Model PR17 (25 HP Motor)
Holding tank	1	2000-gal capacity, steel

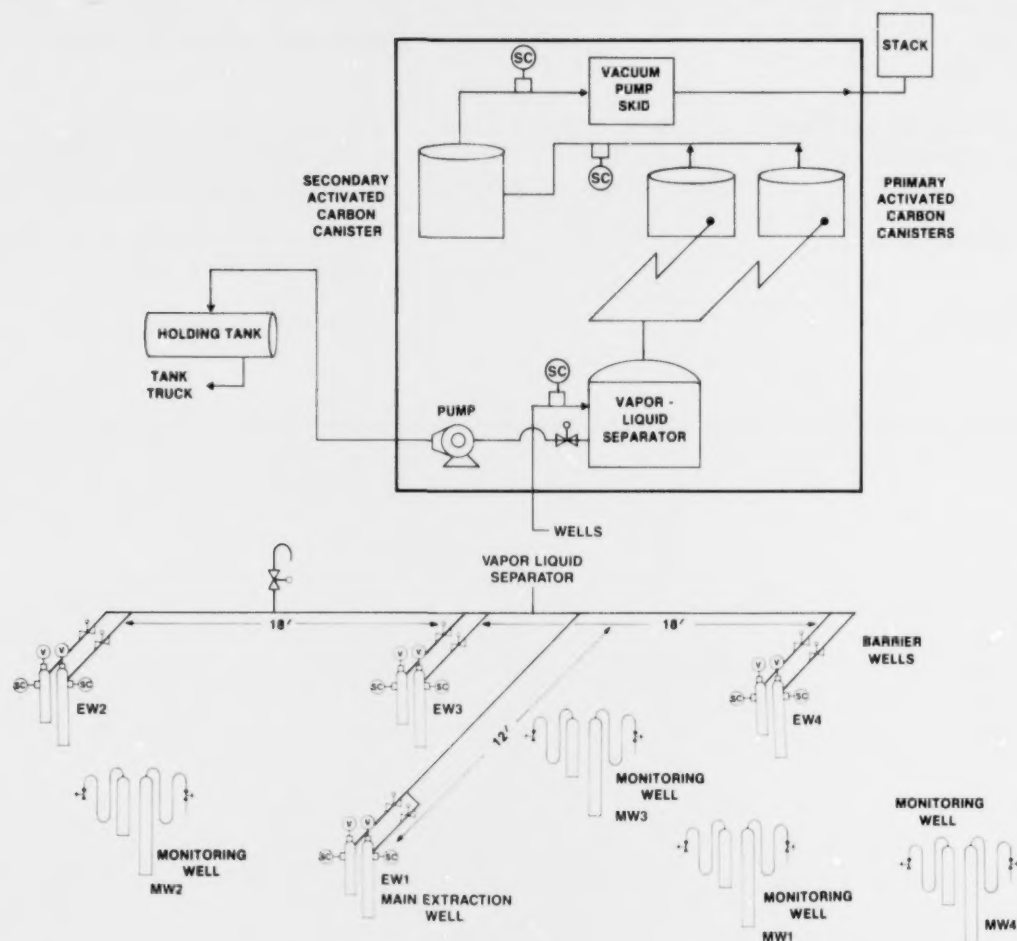


Figure 3.1. Schematic diagram of equipment layout.

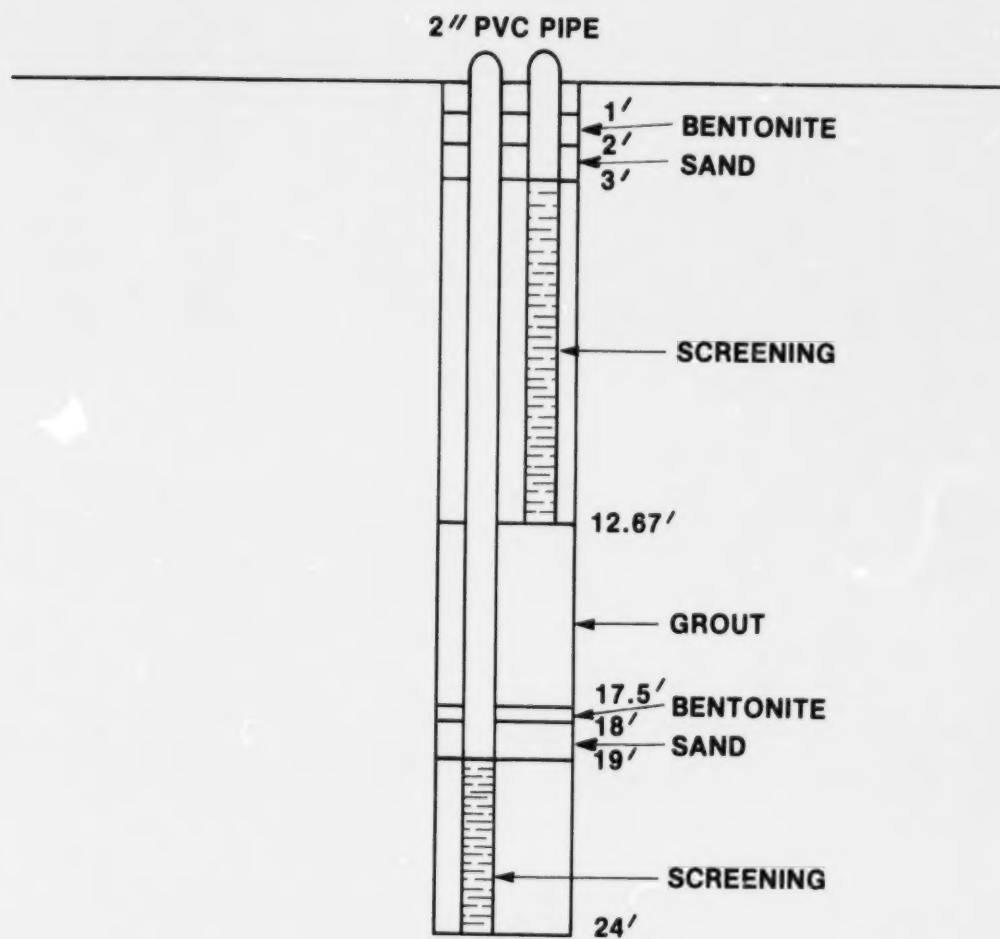
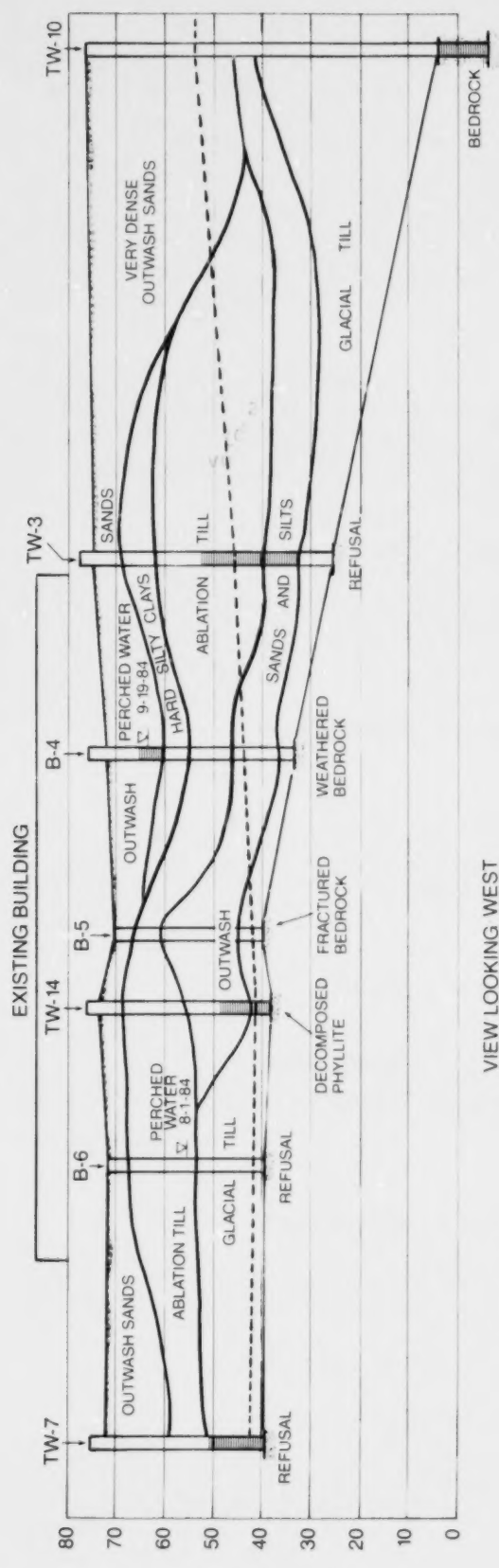
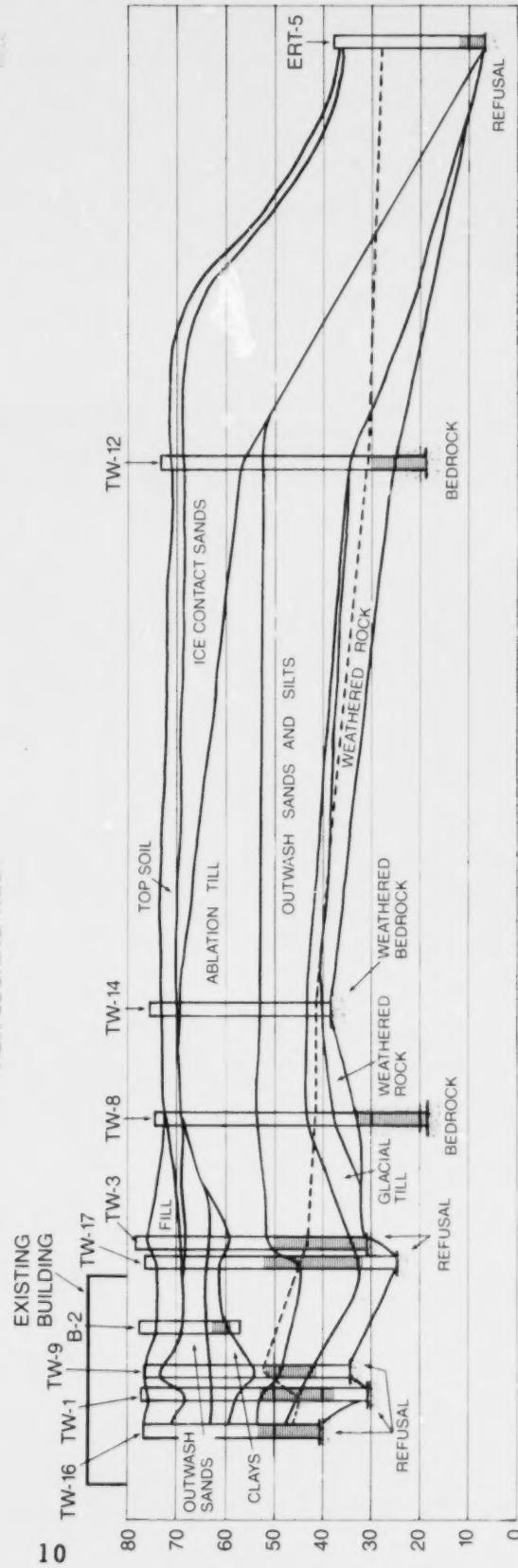


Figure 3.2. Schematic diagram of an extraction well.



VIEW LOOKING WEST



EVALUATIONS REFER TO USGS DATUM

VIEW LOOKING NORTH

SCREENED INTERVAL

----- 1-24-85 WATER TABLE

Figure 3.3. Soil formations.

The clay layer or lens acts as a barrier against gross infiltration of VOCs into subsequent subsoil strata. Most of the subsurface contamination was above the clay layer with the highest concentrations adjacent to it (see Figure 3.4). A considerable amount of water perched on the clay layer and was extracted by the vacuum system.

3.3 THEORY OF VOC EXTRACTION FROM SOIL

In general, VOCs are present in soils as dissolved constituents in an aqueous phase, an adsorbed constituent to solid soil material, and as a free constituent existing in the liquid and vapor phase in the void space of the soil.

If no motive force is being supplied to aid in removing VOCs from the soil matrix then the movement of VOCs through the soil is controlled by diffusion rates. The expressions that are generally used to describe the movement of chemical vapor through the soil are as follows:

$$G_v = \frac{D_v dC_v}{dz}$$

where:

$$\begin{aligned} G_v &= \text{vapor flux in mass/area-time} \\ D_v &= \text{diffusion coefficient area/time} \\ C_v &= \text{concentration of vapor in soil air mass/volume} \\ Z &= \text{distance in the direction of diffusion} \end{aligned}$$

The gaseous diffusion coefficient is given by the following expression:

$$D_v = \frac{a^{10/3}}{\phi^2} D_v^{\text{air}}$$

where:

$$\begin{aligned} a &= \text{air content of soil, volume}^{-1} \\ \phi &= \text{soil porosity} \\ D_v^{\text{air}} &= \text{diffusion coefficient of chemical in free air} \end{aligned}$$

The phase relations of chemicals existing in the soil matrix-water system is generally defined by the following:

$$C_a = K_d C_l$$

where:

$$\begin{aligned} C_a &= \text{mass adsorbed per mass of soil} \\ C_l &= \text{mass dissolved per volume of solution} \\ K_d &= \text{distribution coefficient} \end{aligned}$$

This is a simple linear adsorption model that works well for chemicals at dilute concentrations.

A modified distribution coefficient that takes into account the fact that

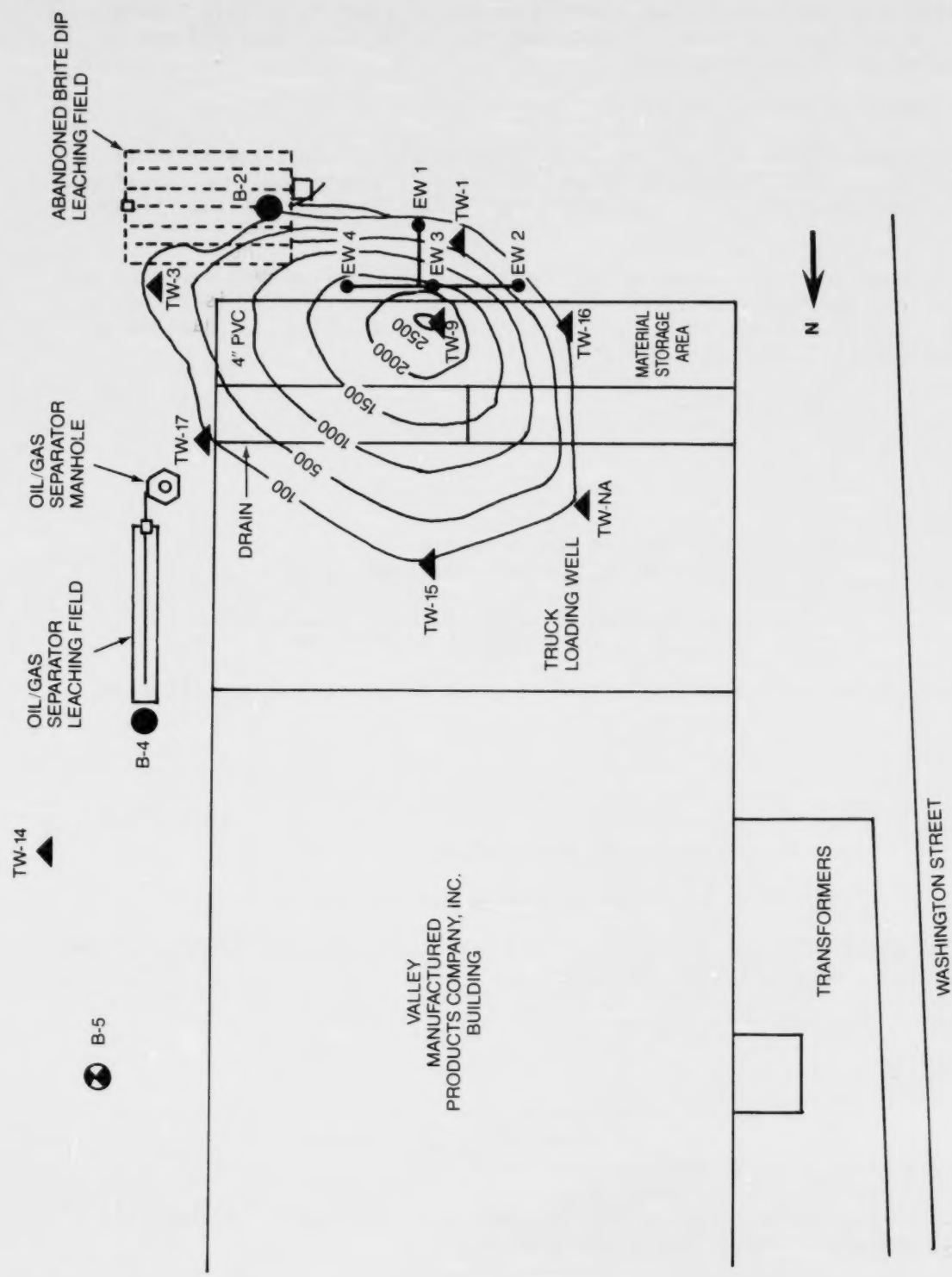


Figure 3.4. Soil contamination contours (ppm).

organic chemicals mostly adsorb to organic material is:

$$K_d = F_{oc} K_{oc}$$

where:

$$\begin{aligned} F_{oc} &= \text{fraction organic content} \\ K_{oc} &= \text{normalized partition coefficient for organic content} \end{aligned}$$

Important relationships involving the solubility of vapors or gases in liquids may also be used to describe the phase relations of chemicals between soil, water, and air. These are Henry's Law and Raoult's Law. Henry's Law states that the equilibrium value of the mole fraction of gas dissolved in a liquid is directly proportional to the partial pressure of that gas above the liquid surface or

$$x_a = P_a/H$$

where:

$$\begin{aligned} x_a &= \text{mole fraction of component A in liquid} \\ P_a &= \text{partial pressure of component A} \\ H &= \text{Henry's Constant, characteristic of system} \end{aligned}$$

The relationship is satisfactory at low concentrations, corresponding to low partial pressures of gas and high values of H.

Raoult's Law, which is for ideal solutions, states

$$\frac{y_a}{x_a} = \frac{P_a^*}{P_t}$$

where:

$$\begin{aligned} y_a &= \text{mole fraction of component A in vapor} \\ P_a^* &= \text{vapor pressure of component A} \\ P_t &= \text{total pressure in system} \end{aligned}$$

Raoult's Law is fairly good with nonpolar gases in nonpolar liquids. For the solubility of nonpolar gases in polar liquids such as water, which forms highly non-ideal solutions, a correction factor (CF), arrived at empirically, is applied:

$$\frac{y_a}{x_a} = CF \frac{P_a^*}{P_t}$$

Equating Henry's Law and Raoult's Law it can be seen that the value of Henry's Constant becomes equal to the pure component vapor pressure multiplied by an empirically arrived at correction factor.

since $P_a = P_t y_a$

then $P_a = P_a^* x_a \text{ CF}$

and $x_a = \frac{P_a}{H} = \frac{P_a^*}{P_a^*} \text{ CF}$

therefore $H = P_a^* \text{ CF}$

A different view of Henry's Law is necessary in order to develop the concepts of partition coefficients, which expresses the relationship between total concentrations of a compound and the concentration of that compound in each phase. Henry's Law may be written as:

$$C_v = K_H C_l$$

where:

C_v = mass in vapor per volume of air
 K_H = Henry's constant

An equation may be written to express the relationship between the total concentration and concentrations in the individual soil, water, and air phases.

$$C_T = d_B C_a + f_w C_l + f_a C_v$$

where:

d_B = soil dry bulk density, mass per vol.
 f_w = volumetric water content in soil, vol. per vol.
 f_a = volumetric air content of soil, vol. per vol.

The vapor partition coefficient relationship can be arrived at by substituting equilibrium relationships in the above equation, e.g.,

For the vapor phase

$$C_T = d_B K_d C_v / K_H + f_w C_v / K_H + f_a C_v$$

$$C_T = (d_B K_d / K_H + f_w / K_H + f_a) C_v$$

$$C_T = R_v C_v$$

where:

R_v = vapor partition coefficient

For the liquid phase

$$C_T = d_B K_D C_l + f_w C_l + f_a K_H C_l$$

$$C_T = (d_B K_D + f_w + f_a K_H) C_l$$

$$C_T = R_1 C_1$$

where:

R_1 = liquid partition coefficient

The vacuum extraction technology works best when it is applied to the remediation of sites that are contaminated with liquids having both high values of Henry's Constant and high vapor pressures.

SECTION 4

FIELD OPERATIONS DOCUMENTATION

4.1 OPERATIONAL HISTORY

Field activities began at the Groveland, MA, site during the early part of November 1987 with mobilization activities and concluded with the removal of the spent activated carbon canisters on May 10, 1988. Table 4.1 provides a chronological history of the project. A few major disruptions in operation occurred during the course of the program, which either lengthened the time in the field substantially or had a negative impact on the extraction process.

- o On December 18 it was decided to suspend operations for the holidays and return in time to start up operations on January 4, 1988. This suspension of operations occurred right after the finish of the commissioning or well development period and the decision was made not to start the active treatment period so close to the holidays.
- o On January 5 upon returning to the site, a section of the header connecting the barrier wells to the main extraction well was found plugged with ice. It was decided to electrically trace all of the piping from the wells to the separator to prevent a recurrence. Active treatment commenced on January 8.
- o On January 15 the system was shut down because excessive quantities of water were being extracted from the ground and were overloading the vapor liquid separator. In addition the life of the small carbon canisters was very short owing to the higher-than-expected amounts of volatile organics being extracted on the site. Larger activated carbon canisters and a larger vapor liquid separator were eventually installed. The new canisters were nominal 1000-lb units and were configured as two parallel primary units followed by a single backup secondary unit. This replaced a four-parallel 200-lb unit primary and four-parallel 200-lb unit secondary. The new separator had a 1000-gallon capacity, five times greater than the original, and was fitted with a level switch to start a pump on high and stop the pump on low level. The water pump discharged to a new 2000-gallon storage tank.
- o Operations were resumed on February 11, 1988 and a new 56-day demonstration test run was started from the beginning.
- o On March 3 the flow from well EW4D stopped because of siltation. During the midtreatment shutdown, the well was pulsed with a water pump to remedy the situation, but the attempt was unsuccessful. This undoubtedly had an effect on the cleanup efficiency in the study area. As a result of the pluggage, EW4D failed to prevent contaminant migration into the study area and failed to extract the contamination from the area around MW3. The only remedy for this situation would have been to drill a new well adjacent to the existing one, but this was impossible to do given the press of time.

TABLE 4.1 CHRONOLOGICAL OPERATIONAL HISTORY

Date	Activity
November 1987	Site mobilization
December 1-10, 1987	Pretreatment soil borings and well installation
December 11-15, 1987	Pretreatment shallow soil gas samples
December 16-18, 1987	Well commissioning
December 18-January 4	Operations suspended for holidays
January 5-7, 1988	System thawing and heat tracing
January 7, 1988	Noise complaint. Shutdown
January 8-15, 1988	Started active treatment period
January 15, 1988	Shutdown for scale-up of system
January 15-February 10, 1988	System redesigned
February 11, 1988	Active treatment started
February 26, 1988	Separator pump malfunction, system off
February 29, 1988	Test resumed
March 3, 1988	Siltation stops flow from EW4D
March 11, 1988	System shutdown at midtreatment
March 14-16, 1988	Soil borings taken
March 15-17, 1988	Shallow soil gas samples taken
March 18, 1988	Active treatment Phase 2 started
April 4, 1988	Electrical interruption pump system off
April 5, 1988	Pump repaired, system back on
April 18, 1988	System shutdown, demonstration run complete
April 19-26, 1988	Posttreatment boring program
April 19-22, 1988	Shallow soil gas samples collected
April 26-May 10, 1988	Site demobilization

4.2 OPERATING CONDITIONS SUMMARY

Table 4.2 presents the operating conditions recorded during the 56-day active treatment period. Data was recorded daily by both Alliance and Terra Vac personnel. Following are comments on the operating data. The first three lines of data contain the date the data was taken, the barometric pressure in inches of mercury, and the ambient temperature.

4.2.1 System Variables

The temperature line is the wellhead temperature measured at the vapor liquid separator inlet. This remained relatively constant throughout the test, at between 35°F and 45°F with most readings at 40°F. The vacuum line item is vacuum in inches of mercury at the separator, and this was a function of the greatest vacuum pulled on any well. This was controlled by opening or closing a ball valve located at each well. To increase the vacuum and regulate the flow on any well, the ball valve is opened more. Terra Vac's instructions were to keep the deep wells at about 2.5 inches of Hg vacuum and the shallow wells at about 4 inches of Hg vacuum in order to promote an upward mobility profile for the contamination.

The percent moisture by Modified Method 4 measures the total moisture in the wellhead gas including the liquid water brought up from the depths by the vacuum system. The result is expressed as a volumetric percentage.

4.2.2 Monitoring Wells

The vacuum in inches of H₂O column was measured on the monitoring wells with a manometer filled with an aqueous solution of ethylene glycol. A correction factor was made for the specific gravity of the glycol solution. The effects of increasing the vacuum in the deep extraction wells during the last two weeks of the demonstration can be seen in the increased vacuum measured in the deep monitoring wells. The increased vacuum in the deep wells doubled the ground water extracted from the deep wells.

TABLE 4.2

GROVELAND/TERRA-VAC PROGRAM

SITE DEMONSTRATION TEST PROGRAM
TERRA VAC UNIT OPERATING CONDITIONS

Day No.	1	2	3	4	5	6	7	8	9
Date	2/11/88	2/12/88	2/13/88	2/14/88	2/15/88	2/16/88	2/17/88	2/18/88	2/19/88
Pbar(in. Hg.)	30.85	30.08	29.36	29.98	30.03	29.75	30.36	30.35	30.49
Temp(F)	36	34	32	26	40	40	32	42	34
SYSTEM VARIABLES									
Temp(F)	35	35	38	35	38	40	40	41	40
Vacuum(in. Hg.)	6	5.5	5	4.75	5.5	6	4.5	5	4.5
% Moisture(MM4)	1.15	1.67	1.9	2.8	3.1	2.5	2.31	2.8	1.44
MONITORING WELLS-VACUUM (in. Water)									
VMW1S	2.3	2	2.4	2.5	2.5	2.4	2.6	2.6	2.7
VMW1D	4.5	4.3	5.2	5.4	4.7	5.1	5.4	5	5
VMW2S	5.6	5.4	5.5	5.4	5.7	4.3	3.8	4.3	3.9
VMW2D	8.3	8.2	8.9	9.4	8.4	9	9.2	8.7	8.7
VMW3S	6.5	6.9	7.3	7.4	8	7	7	7.2	7.5
VMW3D	10	9.8	10	10	10	10	10	10.5	10
VMW4S	0.8	0.6	0.8	0.7	0.8	0.7	0.8	0.9	0.8
VMW4D	4	3.6	4.3	4.6	4.1	4.3	4.5	4.2	4.1
EXTRACTION WELLS									
EW1D	Vacuum(in. Hg.)	2.5	1.5	3	3.5	2.5	3	3	2.5
	Flow(GPM)	16	34	34	31	40	33	26	28
	% Moisture	0.72	0.71	0.87	0.77	0.83	0.93	0.91	0.89
EW1S	Vacuum(in. Hg.)	5.5	5	5	5	5	5.5	4.5	4.5
	Flow(GPM)	8	10	10	9	9	10	8	8
	% Moisture	0.8	0.82	0.94	0.81	0.91	1.02	0.96	1.01
EW2D	Vacuum(in. Hg.)	2.5	2.5	3	2.5	2.5	3	3	2
	Flow(GPM)	17	18	22	18	16	19	15	20
	% Moisture	0.72	0.74	0.87	0.74	0.83	0.93	0.91	0.9
EW2S	Vacuum(in. Hg.)	6	5	5	4.5	5	5.5	4.5	5
	Flow(GPM)	19	15	15	9	18	14	8	10
	% Moisture	0.82	0.82	0.94	0.8	0.91	1.02	0.96	1.01
EW3D	Vacuum(in. Hg.)	2.5	3.5	4	3.5	2	3	3.25	2
	Flow(GPM)	10	10	6	5	6	8	5	7
	% Moisture	0.72	0.77	0.9	0.77	0.81	0.93	0.91	0.9
EW3S	Vacuum(in. Hg.)	5	5	4.5	4.5	5	5.5	4.5	5
	Flow(GPM)	9	8	10	8	7	5	4	5
	% Moisture	0.79	0.82	0.92	0.8	0.91	1.02	0.96	1.01
EW4D	Vacuum(in. Hg.)	2	1.5	1.5	3.5	2.5	3.5	2	3.5
	Flow(GPM)	8	10	7	7	16	8	9	8
	% Moisture	0.8	0.71	0.81	0.77	0.83	0.94	0.87	0.96
EW4S	Vacuum(in. Hg.)	5	5	4.5	4.5	5	5.5	4.5	4.5
	Flow(GPM)	7	8	10	8	8	7	7	7
	% Moisture	0.79	0.82	0.92	0.8	0.91	1.02	0.96	0.99

1 in H₂O = 0.0361 PSI

1 in Hg = 0.491 PSI

TABLE 4.2 (cont.)

GROVELAND/TERRA-VAC PROGRAM

SITE DEMONSTRATION TEST PROGRAM
TERRA VAC UNIT OPERATING CONDITIONS

Day No.		10	11	12	13	14	15	16	17	18
Date		2/20/88	2/21/88	2/22/88	2/23/88	2/24/88	2/25/88	2/26/88	2/27/88	2/28/88
Pbar(in. Hg.)		29.54	29.78	30.29	29.92	30.15	30.25	30.38	30.17	30.35
Temp(F)		42	28	27	50	35	30	30	54	39
SYSTEM VARIABLES										
Temp(F)		40	40	36	43	40	38	40	40	40
Vacuum(in. Hg.)		4.5	4	4.5	5	4.5	4.5	5	5	5
% Moisture(MM4)		1.4	0.77	0.72	1.6	1.3	0.98	1.3	1.6	1.04
MONITORING WELLS-VACUUM (in. Water)										
VMW1S		3.4	3	3.2	3.2	2.8	3.1	3.6	3.8	4
VMW1D		5.2	5.4	5	4.4	4.8	5.5	5.2	4.4	4.1
VMW2S		4.3	3.1	5.1	4.9	4.8	4.7	6.3	6.5	7.3
VMW2D		8.7	10	8.9	7.7	8.7	9.8	9.3	7.9	7
VMW3S		8.3	8	8.9	9.1	8.7	8.3	10.2	9.2	10
VMW3D		10.5	10	10.5	9.3	10.1	10.5	10.1	10	8.1
VMW4S		1	0.9	0.9	1	0.7	0.8	0.8	0.9	1.1
VMW4D		4.2	4.6	4.2	3.6	3.9	4.4	4	3.6	3.3
EXTRACTION WELLS										
EW1D	Vacuum(in. Hg.)	2.5	2.5	3.5	2.5	2.5	2.5	2	3	3
	Flow(GPM)	29	28	26	26	25	26	30	27	28
	% Moisture	0.92	0.91	0.79	1	0.89	0.82	0.87	0.91	0.9
EW1S	Vacuum(in. Hg.)	4.5	3.5	5	4.5	4	3.5	4.5	4.5	4.5
	Flow(GPM)	8	8	9	9	9	9	12	10	12
	% Moisture	0.99	0.94	0.84	1.09	0.94	0.85	0.95	0.97	0.96
EW2D	Vacuum(in. Hg.)	2.5	2.5	3.25	3.5	2.7	2.5	2.5	3.5	3
	Flow(GPM)	16	15	15	18	20	16	16	16	14
	% Moisture	0.94	0.91	0.78	1.05	0.9	0.82	0.88	0.93	0.9
EW2S	Vacuum(in. Hg.)	4.5	4	4.5	4.5	4	4	4.5	4.5	4.5
	Flow(GPM)	8	12	12	10	9	9	12	16	16
	% Moisture	0.99	0.96	0.82	1.09	0.94	0.87	0.95	0.97	0.96
EW3D	Vacuum(in. Hg.)	2.5	2.5	3.5	2.5	3	3	3	2	4.5
	Flow(GPM)	6	6	5	8	6	5	5	9	6
	% Moisture	0.92	0.91	0.79	1.01	0.91	0.84	0.9	0.88	0.96
EW3S	Vacuum(in. Hg.)	4.5	4	4	4.5	4	4	4.5	4.5	4.5
	Flow(GPM)	4	5	6	5.5	6	6	6	10	8
	% Moisture	0.99	0.96	0.8	1.09	0.94	0.87	0.95	0.97	0.96
EW4D	Vacuum(in. Hg.)	2	2.5	3.5	3	3	3	2.5	4	3.5
	Flow(GPM)	6	6	5	6	5.5	5	5	5	4
	% Moisture	0.9	0.91	0.79	1.03	0.91	0.84	0.88	0.95	0.92
EW4S	Vacuum(in. Hg.)	4.5	4	4	4.75	4	4	4.5	4.5	4.5
	Flow(GPM)	6	8	7	7	7	7	8	12	9
	% Moisture	0.99	0.96	0.8	1.11	0.94	0.87	0.95	0.97	0.96

1 in H₂O = 0.0361 PSI

1 in Hg = 0.491 PSI

TABLE 4.2 (cont.)

GROVELAND/TERRA-VAC PROGRAM

SITE DEMONSTRATION TEST PROGRAM
TERRA VAC UNIT OPERATING CONDITIONS

Day No.	19	20	21	22	23	24	25	26	27
Date	2/29/88	3/3/88	3/4/88	3/5/88	3/6/88	3/7/88	3/8/88	3/9/88	3/10/88
Pbar(in. Hg.)	30.38	30.29	30.24	30.38	30.48	30.12	30.66	30.25	29.64
Temp(F)	27	52	33	32	48	46	48	53	48
SYSTEM VARIABLES									
Temp(F)	35	42	35	36	40	40	40	40	40
Vacuum(in. Hg.)	5.5	5.5	6	5.5	5.5	5	5.5	5.5	5.5
% Moisture(MM4)	1.3	0.87	1.3	1.04	1	1.2	0.7	1.2	1.3
MONITORING WELLS-VACUUM (in. Water)									
VMW1S	4	4.3	4.6	4.4	4.2	4.3	4.1	3.9	4.1
VMW1D	4.2	4.1	4	4.4	4.6	4.7	5.2	4.8	5.1
VMW2S	7.1	7.8	8	7.9	7.5	7.6	7.2	7.4	7.3
VMW2D	7.4	7.3	6.9	7.6	8.5	8.8	9.7	9.4	9.5
VMW3S	10	10	10	10	10	10	10	10	10
VMW3D	8.5	8.1	7.8	8.5	9.2	9.3	8.8	9.4	9.9
VMW4S	1	1.2	1.2	1.2	1.2	1.3	1.1	1.1	1.2
VMW4D	3.5	3.3	3.1	3.4	3.6	3.7	4.1	3.7	4.1
EXTRACTION WELLS									
EW1D	Vacuum(in. Hg.)	3	2.5	2	2.5	2.5	3	2.5	2.5
	Flow(GPM)	28	23	27	29	31	28	28	30
	% Moisture	0.74	0.96	0.72	0.76	0.89	0.91	0.88	0.89
EW1S	Vacuum(in. Hg.)	3.5	4.5	5	5	5	5	4.5	5
	Flow(GPM)	13	12	16	13	13	12	14	12
	% Moisture	0.82	1.04	0.81	0.83	0.97	0.98	0.97	0.96
EW2D	Vacuum(in. Hg.)	3.5	2.5	3	3	2.5	3	2.5	2.5
	Flow(GPM)	13	16	14	20	21	18	20	21
	% Moisture	0.75	0.96	0.75	0.77	0.89	0.91	0.88	0.89
EW2S	Vacuum(in. Hg.)	5.5	5	5	5	5	5	5	5
	Flow(GPM)	11	20	18	16	16	16	18	16
	% Moisture	0.82	1.06	0.81	0.83	0.97	0.98	0.97	0.98
EW3D	Vacuum(in. Hg.)	4	2	3	4	2.5	3	4.2	2
	Flow(GPM)	4	5	5	4	6	5	4	6
	% Moisture	0.74	0.95	0.75	0.8	0.89	0.91	0.94	0.87
EW3S	Vacuum(in. Hg.)	5.5	5	5	5	5	5	5	5
	Flow(GPM)	8	8	10	10	9	8	8	7
	% Moisture	0.82	1.06	0.81	0.83	0.97	0.98	0.97	0.98
EW4D	Vacuum(in. Hg.)	1	5	5	3.5	3	2.5	2.5	5
	Flow(GPM)	4	0	1	0	0	0	0	0
	% Moisture	0.69	1.06	0.81	0.79	0.9	0.89	0.88	0.98
EW4S	Vacuum(in. Hg.)	5.5	5	5	5	5	5	5	5
	Flow(GPM)	9	10	11	10	10	10	10	9
	% Moisture	0.82	1.06	0.81	0.83	0.97	0.98	0.97	0.98

TABLE 4.2 (cont.)

GROVELAND/TERRA-VAC PROGRAM

SITE DEMONSTRATION TEST PROGRAM
TERRA VAC UNIT OPERATING CONDITIONS

Day No.		28	29	30	31	32	33	34	35	36
Date		3/11/88	3/18/88	3/19/88	3/20/88	3/21/88	3/22/88	3/23/88	3/24/88	3/25/88
Pbar(in. Hg.)		30.02	30.2	29.85	29.8	30.4	30.62	30.88	30.24	30.68
Temp(F)		45	46	60	40	16	29	42	68	46
SYSTEM VARIABLES										
Temp(F)		40	40	42	35	35	38	40	45	40
Vacuum(in. Hg.)		5	3.5	4.5	5	4.5	5	5	5	5
% Moisture(MM4)		1.3	1.3	0.97	0.91	1.3	0.99	1.8	1.5	1.22
MONITORING WELLS-VACUUM (in. Water)										
VMW1S		3.4	3.4	3.1	3	3.4	3.4	3.4	3.4	3.5
VMW1D		5.3	5	5	5.3	5.2	5.3	5.2	5.4	4.9
VMW2S		4.7	5.9	5.2	5.1	5.9	5.9	5.9	5.6	5.8
VMW2D		9.5	9.3	9.5	10	9.7	9.8	10	10.2	9.5
VMW3S		10	10.5	9.5	8.8	9.8	10.2	9.9	10	10.5
VMW3D		10	10.1	9.4	9.8	9.7	9.9	9.7	10	9.6
VMW4S		0.7	1.1	0.9	1	0.9	1.1	1.1	1.1	1.1
VMW4D		4.2	4.2	4.1	4.2	4.2	4.2	4.2	4.1	3.9
EXTRACTION WELLS										
EW1D	Vacuum(in. Hg.)	3	2	3	2.5	2.5	3	2.5	2.5	2.5
	Flow(GPM)	26	26	36	28	29	21	30	30	26
	% Moisture	1.1	0.88	1	0.91	0.73	0.83	0.87	1.07	0.88
EW1S	Vacuum(in. Hg.)	4.5	3.5	4	4	4	4.5	5	4.5	5
	Flow(GPM)	11	10	10	11	12	12	15	12	11
	% Moisture	1.2	0.93	1	0.96	0.77	0.89	0.96	1.15	0.96
EW2D	Vacuum(in. Hg.)	2.5	2	2.5	2.5	2.5	2.5	3	3	2.5
	Flow(GPM)	21	18	22	27	26	24	22	20	24
	% Moisture	1.09	0.88	0.97	0.91	0.73	0.82	0.89	1.09	0.88
EW2S	Vacuum(in. Hg.)	4.5	3.5	4.5	4	4	4.5	5	4.5	4.5
	Flow(GPM)	16	14	14	16	15	16	17	15	16
	% Moisture	1.18	0.93	1	0.96	0.77	0.89	0.96	1.15	0.95
EW3D	Vacuum(in. Hg.)	3	2	1.5	3.5	3	2.5	3.5	2.5	2
	Flow(GPM)	4	8	8	7	5	7	5	6	6
	% Moisture	1.11	0.88	0.94	0.94	0.74	0.82	0.91	1.07	0.86
EW3S	Vacuum(in. Hg.)	4.5	3.5	4.5	4	4	4.5	5	4.5	4.5
	Flow(GPM)	8	7	7	6	8	8	8	8	7
	% Moisture	1.18	0.93	1	0.96	0.77	0.89	0.96	1.15	0.95
EW4D	Vacuum(in. Hg.)	2	3	1.5	3.5	2.5	4	2.5	2.5	4.5
	Flow(GPM)	0	1	0	0	0	0	0	0	0
	% Moisture	1.07	0.91	0.94	0.94	0.73	0.86	0.87	0.87	
EW4S	Vacuum(in. Hg.)	4.5	3.5	4.5	4	4.5	4.5	5	4.5	4.5
	Flow(GPM)	10	8	9	10	10	10	10	10	10
	% Moisture	1.18	0.93	1	0.96	0.79	0.89	0.96	1.15	0.95

1 in H₂O = 0.0361 PSI

1 in Hg = 0.491 PSI

TABLE 4.2 (cont.)

GROVELAND/TERRA-VAC PROGRAM

SITE DEMONSTRATION TEST PROGRAM
TERRA VAC UNIT OPERATING CONDITIONS

Day No.		37	38	39	40	41	42	43	44	46
Date		3/26/88	3/27/88	3/28/88	3/29/88	3/30/88	3/31/88	4/1/88	4/2/88	4/4/88
Pbar(in. Hg.)		30.35	29.93	30.38	30.54	30.71	30.64	30.67	30.6	30.14
Temp(F)		66	62	42	62	52	56	58	67	62
SYSTEM VARIABLES										
Temp(F)		45	45	40	45	45	45	43	45	45
Vacuum(in. Hg.)		4.5	6	5.5	5.5	5.5	5.5	5.5	6	3
% Moisture(MM4)		1.9	1.47	1.22	0.64	1.53	1.07	1.4	0.97	*
MONITORING WELLS-VACUUM (in. Water)										
VMW1S		3.2	3.5	3.6	3.8	3.3	3.4	3.3	1.5	2
VMW1D		6	5.6	5.1	5.2	5	4.7	5.2	3.7	3.8
VMW2S		4.7	7.3	6.6	6.6	6.1	6.5	6.2	4.1	3.9
VMW2D		10	10	10	9.6	9.3	8.6	9.8	7.2	7.3
VMW3S		9.2	10	10	10	10	10	10.1	10	7.1
VMW3D		10	10	9.9	10	9.6	9	9.6	9.3	7.5
VMW4S		1.2	1.1	1	1.1	0.7	1	1	0.6	0.5
VMW4D		4.7	4.5	4.1	4.2	3.9	3.9	4.2	2.8	3
EXTRACTION WELLS										
EW1D	Vacuum(in. Hg.)	3	2	2.5	2.5	3	3	2.5	2.5	2
	Flow(GPM)	29	26	25	25	28	28	31	22	20
	% Moisture	1.1	1.12	0.88	1.07	1.08	1.09	1	1.06	1.07
EW1S	Vacuum(in. Hg.)	4	5	5	5	5	5	5	5	3
	Flow(GPM)	13	11	12	12	13	13	13	13	8
	% Moisture	1.1	1.2	0.97	1.18	1.17	1.17	1.1	1.17	1.11
EW2D	Vacuum(in. Hg.)	3	3	3	3	3	3	3	3	2
	Flow(GPM)	20	22	20	18	20	19	19	21	15
	% Moisture	1.1	1.12	0.9	1.09	1.08	1.09	1	1.09	1.07
EW2S	Vacuum(in. Hg.)	4	5	5	5	5	5.5	5	5	3
	Flow(GPM)	12	14	14	14	15	15	16	16	9
	% Moisture	1.1	1.2	0.97	1.18	1.17	1.19	1.1	1.17	1.11
EW3D	Vacuum(in. Hg.)	3	2.5	3	3	1.5	4.5	3.5	4	3
	Flow(GPM)	5	7	6	5	6	5	4	2	4
	% Moisture	1.1	1.1	0.9	1.09	1.03	1.15	1	1.12	1.11
EW3S	Vacuum(in. Hg.)	7	5.5	5	5	5	5.5	5	5	3
	Flow(GPM)	8	6	7	8	8	8	8	6	5
	% Moisture	2.2	1.23	0.97	1.18	1.17	1.19	1.1	1.17	1.11
EW4D	Vacuum(in. Hg.)	1	5	4.5	2.5	5	5	5	5	3
	Flow(GPM)	0	0	0	0	0	0	0	0	0
	% Moisture	1		0.95	1.07	1.17	1.17	1.1	1.17	1.11
EW4S	Vacuum(in. Hg.)	4	5.5	5	5	5	5.5	5	5	3
	Flow(GPM)	11	8	8	8	10	9	9	10	6
	% Moisture	1.1	1.23	0.97	1.18	1.17	1.19	1.1	1.17	1.11

1 in H₂O = 0.0361 PSI

1 in Hg = 0.491 PSI

TABLE 4.2 (cont.)

GROVELAND/TERRA-VAC PROGRAM

SITE DEMONSTRATION TEST PROGRAM
TERRA VAC UNIT OPERATING CONDITIONS

Day No.	47	48	49	50	51	52	53	54	55
Date	4/5/88	4/6/88	4/7/88	4/8/88	4/9/88	4/10/88	4/11/88	4/12/88	4/13/88
Pbar(in. Hg.)	30.07	30.32	30.08	30.02	30	30.3	30.2	30.45	30.38
Temp(F)	62	44	44	43	54	60	42	43	44
SYSTEM VARIABLES									
Temp(F)	45	40	40	40	42	42	40	40	40
Vacuum(in. Hg.)	4.5	4	4.5	4.5	4.5	4.5	4.5	4.5	5
% Moisture(MM4)	1.42	1.05	1.09	1.5	1.53	1.2	1.33	1.1	1.25
MONITORING WELLS-VACUUM (in. Water)									
VMW1S	3.3	2	2	2.2	1.9	2	2	2	1.5
VMW1D	4.4	6	6.6	6.5	6.7	6.5	6.7	6.8	7
VMW2S	6.6	4	3.7	3.9	3.8	3.6	3.8	3.7	3.2
VMW2D	8.7	12.7	12.5	12.5	12.7	12.5	12.5	13.1	13.5
VMW3S	10	7.2	6.9	7.5	7.1	7.5	7.1	7.2	6.9
VMW3D	8.7	12	11.5	12	12	12	11.8	12.5	13
VMW4S	1.1	0.6	0.5	0.6	0.7	0.5	0.7	0.6	0.6
VMW4D	3.8	5.3	5.3	5.2	5.4	5.1	5.3	5.4	5.8
EXTRACTION WELLS									
EW1D	Vacuum(in. Hg.)	3	3.5	4	3.5	4	3.5	3.5	3.5
	Flow(GPM)	28	28	30	30	29	28	28	32
	% Moisture	1.11	0.92	0.95	0.93	1.02	1	0.93	0.9
EW1S	Vacuum(in. Hg.)	4	2.5	2.5	3	2.5	2.5	3	2
	Flow(GPM)	16	9	10	9	12	11	10	8
	% Moisture	1.15	0.89	0.9	0.92	0.97	0.96	0.91	0.9
EW2D	Vacuum(in. Hg.)	3.5	3.5	4	4	4	3.5	4	4
	Flow(GPM)	18	26	26	24	24	24	25	27
	% Moisture	1.13	0.92	0.95	0.95	1.02	1	0.94	0.9
EW2S	Vacuum(in. Hg.)	4	2	3	3	2.5	3	3	2.5
	Flow(GPM)	14	12	10	12	10	11	11	8
	% Moisture	1.15	0.87	0.92	0.92	0.97	0.98	0.91	0.9
EW3D	Vacuum(in. Hg.)	4	3.5	4	4	4.5	4	4	4
	Flow(GPM)	2	4	4	5	4	5	4	4
	% Moisture	1.15	0.92	0.95	0.95	1.04	1	0.94	0.9
EW3S	Vacuum(in. Hg.)	4	2.5	3	2.5	3.5	3	3	3
	Flow(GPM)	8	6	6	6.5	6	6	5	4
	% Moisture	1.15	0.89	0.92	0.9	1.1	0.98	0.91	0.9
EW4D	Vacuum(in. Hg.)	4	3.5	4	4	4.5	4	4	4
	Flow(GPM)	0		0	0	8	0	0	0
	% Moisture	1.15	0.92	0.95	0.95	1.04	1.02	0.94	0.9
EW4S	Vacuum(in. Hg.)	4	2	3	3	3	2.5	3	3
	Flow(GPM)	10	8	10	8	8	8	8	8
	% Moisture	1.15	0.87	0.92	0.92	0.99	0.96	0.91	0.9

1 in H₂O = 0.0361 PSI

1 in Hg = 0.491 PSI

TABLE 4.2 (cont.)

GROVELAND/TERRA-VAC PROGRAM

SITE DEMONSTRATION TEST PROGRAM
TERRA VAC UNIT OPERATING CONDITIONS

Day No.		56	57	60
Date		4/14/88	4/15/88	4/18/88
Pbar(in. Hg.)		30.42	30.35	29.7
Temp(F)		48	47	48
SYSTEM VARIABLES				
Temp(F)		40	40	40
Vacuum(in. Hg.)		4	4.5	4.75
% Moisture(MM4)		1.24	0.99	1.32
MONITORING WELLS-VACUUM (in. Water)				
VMW1S		1.7	1.9	2.2
VMW1D		7	6.8	6.9
VMW2S		3.3	3.7	3.6
VMW2D		13.5	13	13
VMW3S		6.5	7.5	7.9
VMW3D		23	12.5	12.5
VMW4S		0.7	0.7	0.8
VMW4D		5.7	5.5	5.5
EXTRACTION WELLS				
EW1D	Vacuum(in. Hg.)	4	4	4
	Flow(GPM)	30	30	30
	% Moisture	0.93	0.94	0.96
EW1S	Vacuum(in. Hg.)	2.5	3	3.5
	Flow(GPM)	10	10	9
	% Moisture	0.88	0.9	0.95
EW2D	Vacuum(in. Hg.)	4	3.5	4
	Flow(GPM)	25	23	27
	% Moisture	0.93	0.92	0.96
EW2S	Vacuum(in. Hg.)	2	2.5	2.5
	Flow(GPM)	10	10	12
	% Moisture	0.87	0.89	0.91
EW3D	Vacuum(in. Hg.)	4.5	4	4
	Flow(GPM)	4	4	4
	% Moisture	0.95	0.94	0.96
EW3S	Vacuum(in. Hg.)	2	3	3
	Flow(GPM)	5	5	5
	% Moisture	0.87	0.9	0.93
EW4D	Vacuum(in. Hg.)	4.5	4	4
	Flow(GPM)	0	0	0
	% Moisture	0.95	0.94	0.96
EW4S	Vacuum(in. Hg.)	3	2.5	3
	Flow(GPM)	8	8	8
	% Moisture	0.9	0.89	0.93

1 in H₂O = 0.0361 PSI

1 in Hg = 0.491 PSI

SECTION 5

SAMPLING AND ANALYSIS PROGRAM

The SITE Program demonstration test of the Terra Vac in situ vacuum extraction process was conducted over a 56-day operating period beginning on February 11, 1988 and ending on April 18, 1988. A mid-operations break of six days occurred on March 11, 1988 to take midtreatment soil borings and samples. The operations that took place between December 16, 1987 and January 15, 1988 are to be considered an extended commissioning or development period for the extraction wells. The initial active treatment period was aborted on January 15, 1988 for reasons explained in Section 4 of this report.

The sampling and analytical program for the test was split up into a pretest period, which has been called a pretreatment period; an active period; mid-treatment; and a posttreatment period.

The pretreatment period sampling program consisted of:

- o soil boring samples taken with split spoons
- o soil boring samples taken with Shelby tubes
- o soil gas samples taken with punch bar probes

Soil borings (see Figure 5.1) taken by split spoon sampling were analyzed for volatile organic compounds (VOCs) using headspace screening techniques, purge and trap, GC/MS procedures, and the EPA-TCLP procedure. Additional properties of the soil were determined by sampling using a Shelby tube, which was pressed hydraulically into the soil by a drill rig to a total depth of 24 ft. These Shelby tube samples were analyzed to determine physical characteristics of the subsurface stratigraphy such as bulk density, particle density, porosity, pH, grain size, and moisture. These parameters were used to define the basic soil characteristics.

Shallow soil gas concentrations were collected during pre-, mid-, and posttreatment activities. Four shallow vacuum monitoring wells and twelve shallow punch bar tubes were used at sample locations (see Figure 5.2). The punch bar samples were collected from hollow stainless steel probes that had been driven to a depth of 3 to 5 ft. Soil gas was drawn up the punch bar probes with a low-volume personal pump and tygon tubing. Gas-tight 50-ml syringes were used to collect the sample out of the tygon tubing. See Table 5.1 for a summary of pretreatment sampling.

The active treatment period consisted of collecting samples of:

- o wellhead gas
- o separator outlet gas
- o primary carbon outlet gas
- o secondary carbon outlet gas
- o separator drain water

See Figure 5.3.

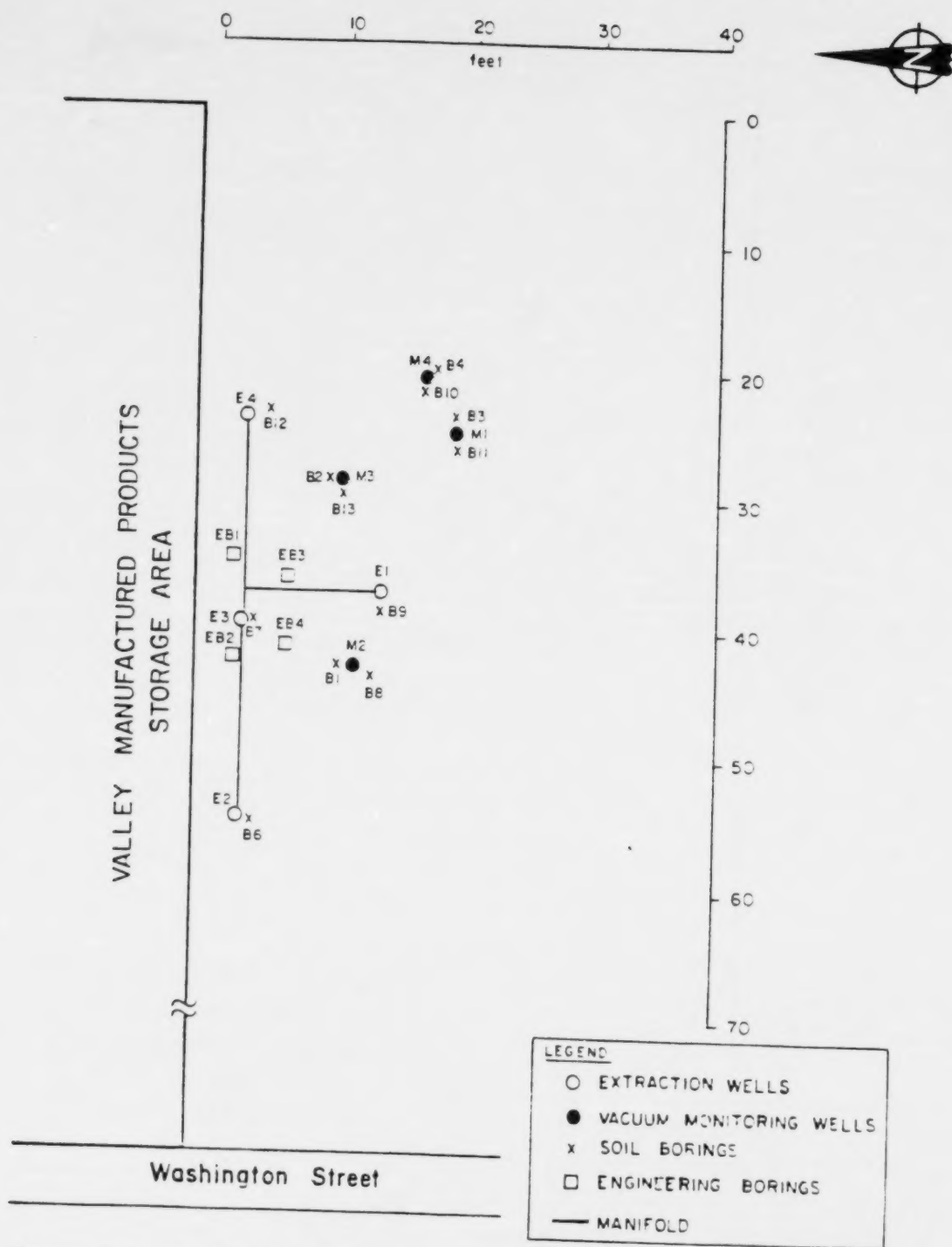


Figure 5.1. Soil boring locations.

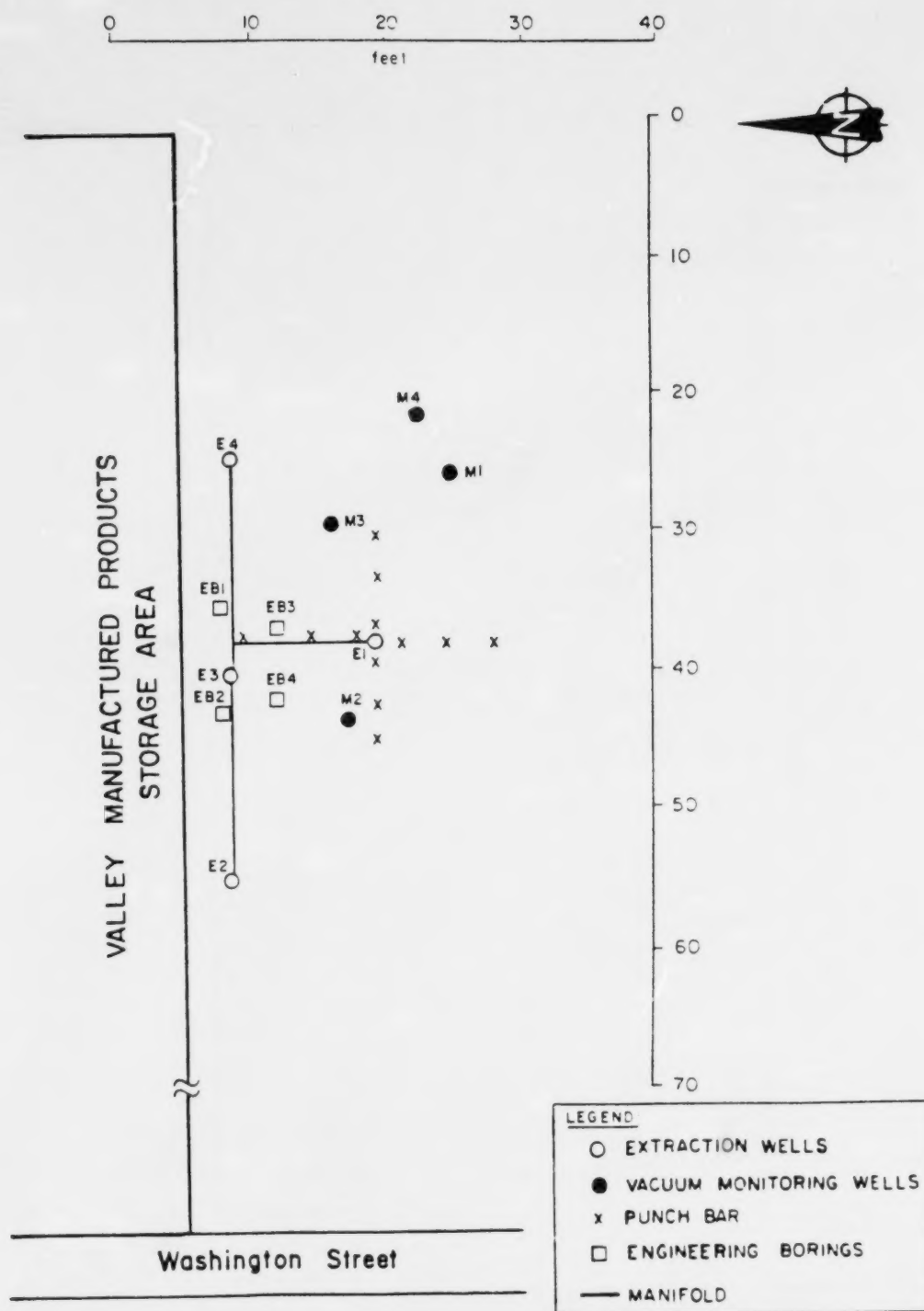


Figure 5.2. Soil gas sampling locations.

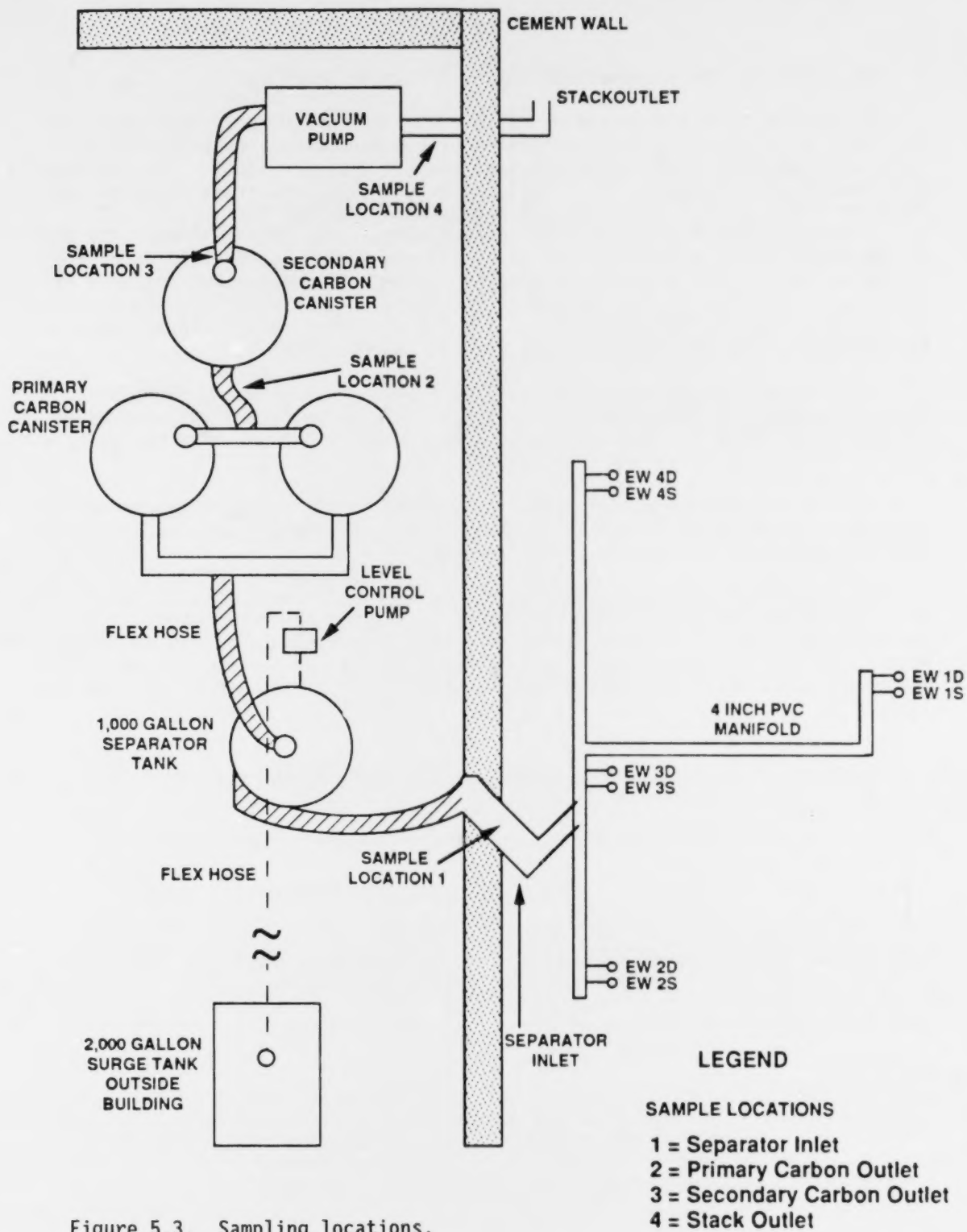


Figure 5.3. Sampling locations.

See Table 5.2 for a summary of active treatment sampling.

All samples with the exception of the separator drain water were analyzed on site. On-site gas analysis consisted of gas chromatography with a flame ionization detector (FID) or an electron capture detector (ECD). The FID was used generally to quantify the trichloroethylene (TCE) and trans 1,2-dichloroethylene (DCE) values, while the ECD was used to quantify the 1,1,1-trichloroethane (TRI) and the tetrachloroethylene (PCE) values. The use of two detectors, FID and ECD, was necessitated by high concentrations of TCE in the extracted well head gas. Owing to the high TCE concentrations most of the samples injected on the ECD had to be diluted. Even with dilution factors of 333 to 1, the TCE concentration on the ECD would exceed the linear range of the detector, thus necessitating the use of two detectors.

The separator drain water was analyzed for VOC content using SW846 8010. Moisture content of the separator inlet gas from the wells was analyzed using EPA Modified Method 4. This method is good for the two-phase flow regime that existed in the gas emanating from the wellhead.

The posttreatment sampling essentially consisted of repeating pretreatment sampling procedures at locations as close as possible to the sampling locations from the pretreatment period. (See Table 5.3.)

The activated carbon canisters were sampled, as close to the center of the canister as possible, and these samples were analyzed for VOC content as a check on the material balance for the process. The method used was P&CAM 127, which consisted of desorption of the carbon with CS₂ and subsequent gas chromatographic analysis. For a listing of all analytical methods applied, see Table 5.4.

TABLE 5.1 PRETREATMENT SAMPLE TYPE, LOCATION, AND FREQUENCY

Sample Type	Sample Location	Sampling Frequency	Number of Samples
Soil Boring (SB)	Extraction wells 1 through 4	Continuously down to 24-ft depth	48
Soil Boring (SB)	Monitoring wells 1 through 4	Same as above	48
Soil Gas (SG)	Twelve strategically located soil gas punch bar probes plus four monitoring wells	Single grab sample at each punch bar location plus two samples at each monitoring well	20

TABLE 5.2 ACTIVE TREATMENT SAMPLING SCHEDULE

Sample Locations	Week 1	Weeks 2 & 3	Weeks 4 & 5	Weeks 6, 7, & 8
EW-1-S, 1-D	Twice per day	Every day	Every other day	Every day
EW-2-S,D	Once per day	Every other day	Every other day	Every other day
EW-3-S,D				
EW-4-S,D				
MW-1-S,D	Once per day	Every other day	Every other day	Every other day
MW-2-S,D				
MW-3-S,D				
MW-4-S,D				
Separator Outlet	Every other day	Once per week	Once per week	Once per week
Primary Carbon Outlet	Every day	Every day	Every day	Every day
Secondary Carbon Outlet	Every other day	Once per week	Once per week	Once per week

TABLE 5.3 POSTTREATMENT SAMPLE TYPE, LOCATION, AND FREQUENCY

Sample Type	Sample Location	Sampling Frequency	Number of Samples
Soil Boring (SB)	Eight sample borings near extraction wells and monitoring wells	Continuously down to same levels at the extraction and monitoring wells*	96
Soil Gas (SG)	Twelve punch bars located adjacent to SG pretreatment sample locations plus four monitoring wells	Single grab samples	35
Separator Liquids (LQ)	Separator drain	Single composite sample representative of completely mixed separator liquid	1
Activated Carbon	Carbon unit	Single composite sample representative of completely mixed activated carbon contents	1

* Sample size and depth may be adjusted as necessary depending on the actual field conditions.

TABLE 5.4 ANALYTICAL METHODS

Parameter	Analytical method	Sample Source
Grain size	ASTM D422-63	Soil borings
pH	SW846* 9040	Soil borings
Moisture (110°C)	ASTM D2216-80	Soil borings
Particle density	ASTM D698-78	Soil borings
Oil and grease	SW846* 9071	Soil borings
EPA-TCLP	F.R. 11/7/86, Vol. 51, No. 216, SW846* 8240	Soil borings
TOC	SW846* 9060	Soil borings
Headspace VOC	SW846* 3810	Soil borings
VOC	GC/FID or ECD	Soil gas
VOC	GC/FID or ECD	Process gas
VOC	SW846* 8010	Separator liquid
VOC	SW846* 8010	Groundwater
VOC	Modified P&CAM 127	Activated carbon
VOC	SW846* 8240	Soil borings

*Third Edition, November 1986.

5.1 SAMPLING PROCEDURES

5.1.1 Soil Borings

Soil borings were taken using a hollow stem auger to a depth of 24 ft. Continuous split spoon samples were taken during the boring activities. Boring and sample collection responsibilities were divided over the course of the program between Terra Vac and Alliance. Alliance accepted the pretreatment split spoon samples from Terra Vac, and was responsible for opening the split spoons, field screening the samples with an OVA, logging of distribution and types of soil, and dividing and bottling the samples for analyses. Standard EPA sample chain-of-custody procedures were used for disbursement of all samples to the appropriate organization for analyses.

During the mid- and posttreatment phases of the operation, Alliance directed a drilling subcontractor to create test borings and collect split spoon samples and was responsible for the field screening and logging of split spoon samples, sampling bottling, chain-of-custody records, and sample disbursement for analyses.

Each soil boring drilled during the mid- and posttreatment phases was back-filled with native soils (see Volume II, Appendix A).

5.1.2 Split Spoon Samples

Soil samples were collected from borings in accordance with the Standard Penetration Test (ASTM D-1586-84). A 24-inch long, 2-inch inside diameter (ID) split spoon sampler was used to collect soil samples. Each sampler was driven 24 inches into the soil by a 140-pound weight falling 30 inches onto the top of the sampler sod. The number of hammer blows needed to advance the sampler each 6-inch interval was recorded.

Once the split spoon sample penetrated 24 inches, it was retrieved, opened, and the sample recovery was measured. The sample then was screened with an Organic Vapor Analyzer (OVA) for the presence of volatile organics. The sample was logged, divided into the quantities necessary for the remaining analyses, and bottled. Once collected, the samples were given a unique sample number, logged onto a chain-of-custody form, and placed in a cooler.

Split spoons were decontaminated after the collection of a sample. The decontamination process consisted of placing all split spoon parts into a wash tub containing AlconoxTM detergent and water. All parts were thoroughly cleaned in this solution using a brush, then rinsed with deionized water and allowed to air dry before reassembly and reuse.

5.1.3 Shelby Tube Samples

Two 24-ft borings were drilled with hollow stem augers for the collection of thin-walled Shelby tube samples during the pretreatment phase of the activity, and an additional two were drilled during the posttreatment phase of the program. These Shelby tube samples were analyzed by a soil laboratory in order to determine the physical characteristics (i.e., moisture, bulk density,

porosity, pH, and grain size) of the subsurface stratigraphy.

Terra Vac was responsible for the drilling of the soil boring and collection and sealing of the thin-walled Shelby tube samples taken during the pre-treatment phase of the program. The Shelby tube samples were sealed by pouring Gulf paraffin wax into the ends of the tube; the two ends of the tube then were capped and taped, and the capped and taped ends were dipped into the wax to complete the seal. Alliance accepted the sealed samples, created the chain-of-custody records, and shipped the sealed samples to the appropriate laboratory for analyses.

Alliance was responsible for the drilling of the second set of borings taken during the posttreatment phase. Alliance was responsible for the sealing, chain-of-custody recordkeeping, and the shipment of these samples.

5.1.4 Soil Gas Samples

Soil gas samples were collected from the monitoring well piezometers using a modification of procedures outlined in the RCRA Facility Investigation Guidance Manual, Volume II (Subsurface Investigations, U.S. EPA Office of Solid Waste, October 1986 and Method IV-11 from EPA-600/4-84-076). These piezometers were installed by Terra Vac to measure soil vacuum at various depths and provided a convenient means of collecting soil gases without further disturbances at the site. The four piezometers were placed strategically at the site in a manner that provided a representative horizontal profile. Each piezometer was the duplicate of an extraction well, and two depths were isolated and monitored independently of the other. Figure 3.1 provides an illustration of the spacial placement of the piezometers around the site.

Soil gas samples were collected by attaching a vacuum pump to tubing from sampling points, indirectly isolated, and drawing a sample to the surface where it was collected in a gas-tight syringe. To facilitate syringe collections, a T-fitting was placed in line between the sampling pump and the downhole tubing. The sampling line was purged with several volumes of sample air prior to the collection of a sample. In general, 20 seconds of purging at a flowrate of approximately 1 liter/minute was adequate to purge the 25 feet of quarter-inch tubing.

Samples were taken using 50-ml gas-tight syringes. The syringe was inserted into the septum end of the T-fitting and purged with at least two purge volumes of sample gas prior to the collection of the actual sample. This syringe then was tagged and delivered to the on-site analytical laboratory for analysis.

Surface soil gas samples were collected from bar punch probe test holes according to Method IV-10 specified in EPA-600/8-84-076. The procedures outlined in the method are described below:

1. Select location free from rocks and debris. Screen locations with metal detector to verify absence of drums and pipes.
2. Place bar point on ground and raise drive weight, then allow weight to fall on bar. It is only necessary to guide the weight in its vertical travel.

3. Continue until desired depth is reached or any penetration resistance occurs.
4. Remove bar hole-maker.
5. Attach suitable length of Teflon tubing (stainless steel or brass may be used in some instances, but may result in some gas adsorption/absorption) to monitor instrument gas inlet.
6. Lower tubing into test hole and operate monitor or gas sampling device as listed in Methods IV-1 through IV-8.
7. Record results.
8. Remove sample tubing and observe that instrument readings return to background. If not, change tubing before proceeding to next test location.
9. Tramp over and recover test hole.

Note that steps 5 and 6 were modified to allow for the collection of gas samples from the monitoring wells via a vacuum pump and gas-tight syringe as described above.

5.1.5 Process Gas Sampling

Process gas samples were collected from various points in the vacuum extraction system using a syringe gas sampling technique. Samples were collected by inserting the gas-tight syringes into gas sampling ports placed at appropriate points in the process. The ports were provided by Terra Vac and were adapted with a septum fitting to allow for insertion of the syringe needle.

The system was under high negative pressure (2- to 12-in. Hg) and care had to be taken when collecting the gas samples. The gas-tight syringes used in this project were modified to allow for the placement of a mininert valve between the needle and luer hub. The valve can be closed after the plunger has been drawn but before the syringe is withdrawn from the sampling port. Since the collected gas was under vacuum, closure of the mininert valve was important to avoid drawing ambient air into the syringe once it was withdrawn from the port. This avoids having to make volume corrections, a potential source of error.

5.1.6 Process Liquids and Activated Charcoal

Process liquids and activated carbon samples were collected and analyzed for volatile organics. Process liquids were collected from the vapor/liquid separator drain. The drain was equipped with a modified stop cock, which enables the drain to be isolated and subsequently opened to allow for the collection of the separator liquids. This valving arrangement is necessary since the unit is under a high negative pressure. Samples were collected using a simple grab sampling technique in which the sample container was used as the collection device.

Spent activated carbon samples were collected from each canister after it was taken off line. Grab samples were collected from as many access points as possible and composited for analysis. Samples were collected using a trier, composited, and placed in a single container for delivery to the laboratory.

5.1.7 Process Data Recording

All process operations data made available by Terra Vac was recorded on a daily basis by Alliance on-site personnel. Data was recorded during all phases of the Terra Vac demonstration. Table 4.2 summarizes the operating data logged through the course of the active treatment period.

Note that Terra Vac was responsible for the operation and accuracy of all temperature, pressure, and flowrate measurement equipment. A portable rotameter manufactured by Fisher and Porter was used for flow measurement. Accuracy of this instrument is ± 2 percent of full-scale (but was not calibrated during this program). Vacuum gauges supplied by Continental Precision Instruments (CPI) were calibrated to Grade B - ANSI B40.1. CPI dial thermometers were employed.

5.2 ANALYTICAL PROCEDURES

5.2.1 VOC Analysis of Soil Samples

VOC analyses on soil samples were conducted using Methods 8240 and 5030 of EPA-SW 846. A portion of the sample was dispersed in methanol to dissolve the volatile organic constituents. An aliquot of the methanolic solution was combined with organic-free water in the purging chamber. Analysis then proceeded using a Hewlett-Packard 5985 gas chromatograph.

Approximately 1 to 5 g of solid sample was transferred into a preweighed 50-ml glass centrifuge tube or 20-ml glass vial, with Teflon-lined caps, containing 15 ml of methanol. The capped centrifuge tube and methanol was reweighed on an analytical balance to determine the sample weight. Care was taken not to touch the sample-transfer implement. The sample was dispersed in the methanol as expeditiously as possible to prevent loss of volatiles from the sample. After the sample weight had been determined, additional methanol was added to the 20 ml mark of the centrifuge tube or glass vial. The sample container was securely recapped and then vigorously agitated for 1 minute, manually or with the aid of a vortex mixer. If the sample did not disperse during this process, the mixture was sonicated in an ultrasonic bath for 30 minutes. The mixture was allowed to stand until a clear supernatant was obtained. The supernatant solution then was analyzed or stored at 4°C for future analytical needs in a 10-ml screw cap vial with Teflon cap liner.

Analysis of the methanol extract proceeded by taking an appropriate aliquot of the methanol solution using a microsyringe. An aliquot of the methanol extract was dispersed directly into 5-ml reagent water in the purging device. The sample then was spiked at 50 ug/l with internal standards and surrogates and purged according to Method 5030 of SW-846 for GC/MS analysis.

Alternatively, the low-level purge-and-trap GC/MS method described in SW-846 8240 was implemented if headspace screening results indicated sample concentrations below 3 to 5 ppm. The low-level technique employs a soil impinger for purge-and-trap GC/MS analysis of a 5-g soil sample. Detection limits for this analysis are typically less than 1 ppm in the absence of matrix interference.

Monitoring of surrogate recoveries will give a good indication of the performance of the analytical system on a sample-by-sample basis. For this analysis, the surrogates and internal standards listed below were added to the purge chamber prior to analysis, with surrogate recoveries monitored to indicate potential problems.

Surrogate Compounds

d₈-toluene

Bromofluorobenzene

d₄-1,2-dichloroethane

Internal Standards

Chlorobromomethane

1,4-difluorobenzene

d₅-chlorobenzene

5.2.2 VOC Analysis of Soils by Headspace Technique

In addition to the analysis of soil gas collected in gas-tight syringes, selected soil samples were collected in pretared vials, allowed to equilibrate, and the overlying headspace analyzed for the five chlorinated organics listed in Section 5.2.4. This screening procedure was used to provide preliminary data prior to purge-and-trap GC/MS analysis.

Headspace analysis of soil samples collected in pretared vials was performed via syringe injection in GC/FID. This method was modified to allow for the use of 5 to 10 g soil portions collected in 40-ml or 20-ml VOA vials, or 10 to 50 g portions collected in 125-ml septum-sealed vials. A portion of headspace from sample vials was injected into the instrument following equilibration of the sample in a 90°C water bath, as detailed in SW-846 Method 3810. The method is a static headspace technique, which is best-suited for compounds with boiling points of less than 125°C. A sample was withdrawn from an equilibrated and sealed glass vial using a gas-tight syringe or headspace autosampler. Detection limits for this analysis of approximately 5 ppm typically can be achieved.

Instrument calibration was performed by spiking dilutions of stock standards into empty headspace vials, which then were equilibrated and analyzed

prior to program samples. A minimum of three standard concentrations were analyzed to calibrate the instrument over the expected range of program samples. Identification and quantitation were provided as with gas sample analyses. Results were provided on a wet weight basis and later converted to dry weights, accounting for soil moisture content. Fortified samples were carried through all stages of sample preparation and measurement and were analyzed to validate the sensitivity and accuracy of the analysis. Field replicates also were collected to validate the precision of the technique.

As Method 3810 does not define expected precision and accuracy for the analysis, a brief program to define these was conducted prior to initiation of the technology evaluation. A minimum of nine VOC-free soils were fortified with a known concentration of the analytes of interest and analyzed using Method 3810.

5.2.3 TCLP

Zero Headspace Extraction--

A total of 103 pretreatment soil samples were shipped from the field to metaTRACE, Inc., Alliance's subcontract laboratory for the purpose of conducting the TCLP analysis. Only 20 of the samples were analyzed with the required holding time, which had a negative impact on the TCLP part of the program (see Vol. II, pp. 4-47).

Samples were extracted using a Zero Headspace Extraction (ZHE) vessel, which effectively precludes headspace during liquid/solid separation and extract filtration. ZHE extract was collected in either Tedlar bags or glass, stainless steel or PTFE gas-tight syringes. ZHE extraction was performed according to the method described in CFR 51 (No. 216, November 7, 1986, pp. 40643-40653). Samples were prepared for extraction by crushing, cutting, or grinding solid portions of the sample to the surface area or particle size specified in the method. The material was then extracted according to the specified method.

VOC Analysis--

Zero headspace extracts were analyzed for trichloroethylene, tetrachloroethylene, 1,2-trans-dichloroethylene, 1,1,1-trichloroethane, and dichloromethane, using SW-846 Method 8240. A 0.5-ml portion of the aqueous extract was diluted to 5.0 ml and surrogate-spiked for purge-and-trap GC/MS analysis. This dilution is required to reduce the concentration of glacial acetic acid in the extraction fluid and consequently reduce instrument downtime. Detection of the regulatory levels presented in Table 5.5 was typically achieved in the leachate.

Calibration--

Calibration procedures described in Method 8240 were employed. Standards were obtained from Supelco, Inc., of Bellefonte, PA.

TABLE 5.5 TCLP REGULATORY LEVELS

Component	Regulatory Level (mg/l)
Trichloroethylene	0.07
Tetrachloroethylene	0.1
1,2-trans-dichloroethylene	(a)
1,1,1-trichloroethane	30
Dichloromethane	8.6

(a) Regulatory level not established. Detection limits of ≤ 0.1 mg/l are anticipated.

5.2.4 VOC Analysis of Soil Gas and Process Gas

During the course of this program, gas samples were collected using gas-tight syringes from soil gas pore space at the site and from various points of the Terra Vac system. Samples were taken at the following points:

- o at the wellheads
- o within soil gas sampling points
- o at the separator inlet
- o at the primary carbon unit outlet
- o at the secondary carbon unit outlet
- o at the vacuum pump outlet

These samples were brought immediately to the Alliance on-site mobile laboratory for analysis. Analyses were conducted as soon as possible to prevent degradation of the samples due to analyte decomposition or wall effects. For that reason, during the active treatment phase of the program, Alliance conducted analyses as soon as was practical on the submitted gas samples.

Sample analytes are those chlorinated organics known to be contaminants of the site soil, namely:

- o trichloroethylene (TCE)
- o perchloroethylene (tetrachloroethylene) (PCE)
- o 1,1,1-trichloroethane (methyl chloroform) (111 TRI)
- o trans-1,2-dichloroethylene (DCE)
- o methylene chloride (dichloromethane) (MeCl)

Samples were analyzed by Gas Chromatography with Electron Capture Detection (GC/ECD) or Flame Ionization Detector (FID) using the techniques described below.

Samples were returned to the laboratory in 50-ml gas-tight syringes fitted with valves to prevent dilution of the sample with ambient air or loss of analyte through an open end. Sample introduction into the gas chromatograph was by use of a (approximately) 1-ml gas sampling loop. The sample gas was introduced to the loop by connection of the syringe to an open end of the loop, opening the syringe valve, and depressing the syringe plunger to fill the loop to excess, thus flushing the loop with sample. While the sample is overflowing from the loop, the injection valve is switched, flushing the loop with column carrier gas and carrying the sample into the GC column. Analysis of the sample then proceeded under the conditions cited in Volume II, Appendix H.

Analytes were identified in each chromatograph run using peak retention times from standards as the benchmark. Quantitation was performed using comparison of the sample peak areas to the calibration curve, described later in this section, using the formula:

$$y = mx + b$$

where: y = concentration of the sample

m = slope of the curve determined by injection of the standard calibration mixes

b = y intercept of the calibration curve

Detection limits for this analysis are anticipated to be in the range of 15,000 to 30,000 micrograms per standard cubic meter for the FID and 8 to 1000 micrograms per standard cubic meter for the ECD (at atmospheric pressure). Corrections for actual pressure were made to calculate actual mass flows. Replicate injections of every fifth sample were made to monitor the precision of the analysis.

The GC/ECD analysis for the organochloride compounds was conducted using a Hewlett-Packard 5890 with an ECD and a Perkin-Elmer 3920 Gas Chromatograph with an FID. The instruments were calibrated daily, or the current calibration checked daily, prior to the analysis of the samples. Calibration and check standards were prepared in the following manner:

1. Prepare a stock solution of chlorinated solvents by combining equal volumes of the components in a septum-sealed vial. The solvents are reagent grade or better, used as obtained from local distributors. Stock solutions are prepared weekly.
2. Add 1.0 ul of the stock solution to a nitrogen-purged Supelco 500 ml gas sampling bulb and allow a 10-minute equilibration period. The concentration of this standard is approximately 1 g/m^3 .
3. Prepare the working standards by serially diluting the 1 g/m^3 gas standard into the 10 to 2,000 ug/m^3 range using Hamilton 1001-LT gas-tight syringes and several nitrogen-purged Tedlar bags. Prepare working standards daily.

5.2.5 VOC Analysis of Separator Liquid

Samples of separator liquid were analyzed by purge-and-trap GC/ECD using SW-846 Method 8010. Volatile compounds were introduced into the GC by Method 5030 (purge-and-trap). The components were separated via the gas chromatograph and detected using a Hall electrolytic conductivity detector using method-specified instrument conditions (SW-846 8010).

Calibration procedures described in the method use a minimum of five concentration levels for each calibration standard. One of the concentration levels was at a concentration close to, but above the detection limit. Five-point calibration curves were constructed for each of the five chlorinated analytes of interest described in Section 5.2.4. The calibration curve for each compound was verified on each working day.

5.2.6 Total Organic Carbon of Soil

Total organic carbon was determined using EPA Method 9060 as follows. The sample was combined with acidified persulfate and purged with helium to transfer inorganic carbon dioxide and purgeable organics to a CO₂ scrubber. The purgeable organics were converted to methane using a nickel catalyst and quantitated using a flame ionization detector. The sample was subsequently transferred to a quartz ultraviolet reaction coil where the nonpurgeables were converted to carbon dioxide in the presence of the acidified persulfate reagent. The carbon dioxide was transferred to a second sparger and carried to the reduction system and detector via a helium purge. The signal was integrated, added to the purgeable organic carbon value, and displayed as the concentration of total organic carbon.

All analyses were performed using a Dohrmann DC-80 Total Organic Carbon Analyzer equipped with a soil/sediment sampler. The instrument was calibrated in accordance with the described method. Prior to beginning sample analysis, the accuracy of the calibration was verified using an EPA demand quality control sample.

5.2.7 Oil and Grease Contents of Soil

Soil samples were prepared and analyzed for oil and grease according to SW-846 Method 9071. The procedure employs soxhlet extraction of an acidified soil sample with fluorocarbon-113. Oil and grease content then was determined by a gravimetric measurement. A distilled water method blank was analyzed to demonstrate that all glassware and solvent were free of contamination.

5.2.8 Moisture

Soil moisture at 110°C was gravimetrically determined using ASTM D2216-80.

5.2.9 Particle Density

Particle density was determined using ASTM D698-78.

SECTION 6

PERFORMANCE DATA AND EVALUATION

6.1 INTRODUCTION

The SITE Program demonstration of the TERRA VAC process had as its main objectives:

- o determination of the ability of the technology to remove volatile organic compounds from the vadose zone
- o assessment of the effectiveness of the technology in various soil types
- o correlation between declining VOC recovery rates and cleanup levels
- o determination of the relationship between VOC concentrations in soils versus concentrations in extract vapors

6.2 VOC REMOVAL FROM THE VADOSE ZONE

The permeable vadose zone at the Groveland site is divided into two layers by a horizontal clay lens, which is relatively impermeable. As explained previously, each extraction well had a separate shallow and deep section to enable VOCs to be extracted from that section of the vadose zone above and below the clay lens. The quantification of VOCs removed was achieved by measuring

- o gas volumetric flow rate by rotameter and wellhead gas VOC concentration by gas chromatography
- o the amount of VOCs adsorbed by the activated carbon canisters by desorption into CS_2 followed by gas chromatography.

VOC flow rates were measured and tabulated for each well section separately. The results of gas sampling by syringe and gas chromatographic analysis, as shown in Tables 6.1 through 6.8, indicate a total of 1,297 lb of VOCs were extracted over a 56-day period, 95% of which was trichloroethylene. A very good check on this total was made by the activated carbon VOC analysis, the results of which indicated a VOC recovery of 1353 lb; virtually the same result was obtained by two vastly different methods.

The most dramatic view of the reduction in VOC concentrations in the vadose zone can be seen from examining the three-dimensional shallow soil gas plots. Soil gas was collected during pretreatment, midtreatment, and posttreatment periods from punch bar probes and shallow vacuum monitoring wells. The collection points were located on a coordinate system with extraction well 1 as the

TABLE 6.1 FLOW RATES AND FLUX RATES, EW1S

FIRST WEEK OF SAMPLING-COLLECTION TWICE PER DAY

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID(a) Lbs/DAY	TOTAL ECD(a) Lbs/DAY
EWG1S/1	2/11/88	27	0.000	0.016	0.002	0.299	0.001	5.574	0.037
EWG1S/2	2/11/88	27	0.000	0.009	0.001	0.141	0.000		
EWG1S/1	2/12/88	35	0.000	0.007	0.000	0.139	0.001	2.938	0.018
EWG1S/2	2/12/88	35	0.000	0.005	0.001	0.094	0.000		
EWG1S/1	2/13/88	35	0.000	0.006	0.001	0.103	0.000	2.506	0.012
EWG1S/2	2/13/88	35	0.000	0.005	0.000	0.096	0.000		
EWG1S/1	2/14/88	31	0.000	0.000	0.000	0.084	0.000	1.824	0.009
EWG1S/2	2/14/88	31	0.000	0.000	0.000	0.068	0.000		
EWG1S/1	2/15/88	31	0.000	0.000	0.000	0.076	0.000	1.663	0.003
EWG1S/2	2/15/88	31	0.000	0.000	0.000	0.063	0.000		
EWG1S/1	2/16/88	34	0.000	0.000	0.000	0.092	0.000	1.978	0.011
EWG1S/2	2/16/88	34	0.000	0.000	0.000	0.073	0.000		
EWG1S/1	2/17/88	28	0.000	0.000	0.000	0.060	0.000	1.368	0.007
EWG1S/2	2/17/88	28	0.000	0.000	0.000	0.054	0.000		

TOTAL Lbs FID VOC 17.851

TOTAL Lbs ECD VOC 0.097

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

(a) Average of two samples collected during the day.

TABLE 6.1 (cont.)

SECOND THROUGH EIGHTH WEEK-COLLECTION ONCE PER DAY

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG1S/1	2/18/88	28	0.000	0.000	0.090	0.052	0.000	1.257	0.006
	2/19/88	28	0.000	0.000	0.000	0.053	0.000	1.269	0.009
	2/20/88	28	0.000	0.000	0.000	0.037	0.000	0.889	0.004
	2/21/88	30	0.000	0.000	0.000	0.048	0.000	1.156	0.004
	2/22/88	31	0.000	0.000	0.000	0.037	0.000	0.878	0.001
	2/23/88	32	0.000	0.000	0.000	0.040	0.000	0.954	0.012
	2/24/88	33	0.000	0.000	0.000	0.056	0.000	1.355	0.006
	2/25/88	33	0.000	0.000	0.000	0.039	0.000	0.927	0.000
	2/26/88	42	0.000	0.000	0.000	0.044	0.000	1.058	0.012
	2/29/88	35	0.000	0.000	0.000	0.046	0.001	1.113	0.023
	3/01/88	42	0.000	0.000	0.000	0.041	0.001	0.993	0.024
	3/02/88	44	0.000	0.000	0.000	0.038	0.001	0.916	0.015
	3/03/88	42	0.000	0.000	0.000	0.027	0.000	0.654	0.004
	3/04/88	55	0.000	0.000	0.000	0.044	0.000	1.067	0.004
	3/05/88	45	0.000	0.000	0.000	0.040	0.000	0.966	0.004
	3/06/88	45	0.004	0.000	0.000	0.037	0.000	0.884	0.093
	3/07/88	41	0.000	0.000	0.000	0.018	0.000	0.439	0.009
	3/08/88	48	0.000	0.000	0.000	0.025	0.000	0.590	0.010
	3/09/88	42	0.000	0.000	0.000	0.052	0.000	1.255	0.012
	3/10/88	31	0.000	0.000	0.000	0.015	0.000	0.369	0.007
	3/11/88	39	0.000	0.000	0.000	0.019	0.000	0.465	0.011

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.1 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG1S/1	3/18/88	37	0.000	0.000	0.000	0.042	0.001	1.018	0.024
	3/19/88	36	0.000	0.000	0.000	0.029	0.001	0.687	0.017
	3/20/88	40	0.000	0.000	0.000	0.077	0.000	1.856	0.013
	3/21/88	44	0.000	0.000	0.000	0.032	0.000	0.758	0.000
	3/22/88	43	0.000	0.000	0.000	0.019	0.000	0.466	0.010
	3/23/88	52	0.000	0.000	0.000	0.388	0.000	9.315	0.014
	3/24/88	42	0.000	0.000	0.000	0.018	0.000	0.425	0.002
	3/25/88	38	0.000	0.000	0.000	0.022	0.000	0.534	0.010
	3/26/88	47	0.000	0.000	0.000	0.019	0.000	0.447	0.010
	3/27/88	38	0.000	0.000	0.000	0.020	0.000	0.478	0.010
	3/28/88	41	0.000	0.000	0.000	0.016	0.000	0.377	0.008
	3/29/88	41	0.000	0.000	0.000	0.014	0.000	0.343	0.001
	3/30/88	45	0.000	0.000	0.000	0.018	0.000	0.437	0.008
	3/31/88	45	0.000	0.000	0.000	0.018	0.000	0.437	0.009
	4/01/88	45	0.000	0.000	0.000	0.014	0.000	0.342	0.008
	4/02/88	45	0.000	0.000	0.000	0.011	0.000	0.274	0.007
	4/04/88	30	0.000	0.000	0.000	0.007	0.000	0.178	0.003
	4/05/88	58	0.000	0.000	0.000	0.015	0.000	0.362	0.008
	4/06/88	35	0.000	0.000	0.000	0.009	0.000	0.209	0.003
	4/07/88	39	0.000	0.000	0.000	0.009	0.000	0.211	0.001
	4/08/88	34	0.000	0.000	0.000	0.009	0.000	0.222	0.003
	4/09/88	46	0.000	0.000	0.000	0.009	0.000	0.225	0.003
	4/10/88	42	0.000	0.000	0.000	0.008	0.000	0.202	0.004
	4/11/88	38	0.000	0.000	0.000	0.007	0.000	0.160	0.003

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.1 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG1S/1	4/12/88	32	0.000	0.000	0.000	0.007	0.000	0.160	0.002
	4/13/88	36	0.000	0.000	0.000	0.010	0.000	0.248	0.003
	4/14/88	39	0.000	0.000	0.000	0.006	0.000	0.149	0.000
	4/15/88	38	0.000	0.000	0.000	0.007	0.000	0.169	0.000
	4/18/88	33	0.000	0.000	0.000	0.005	0.000	0.131	0.000

TOTAL Lbs FID VOC 40.272

TOTAL Lbs ECD VOC 0.453

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.2 FLOW RATES AND FLUX RATES, EW 1D

FIRST WEEK OF SAMPLING-COLLECTION TWICE PER DAY

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID(a) Lbs/DAY	TOTAL ECD (a) Lbs/DAY
EWG1D/1	2/11/88	62	0.000	0.021	0.003	0.292	0.000	5.737	0.041
EWG1D/2	2/11/88	62	0.000	0.014	0.000	0.148	0.000		
EWG1D/1	2/12/88	137	0.000	0.038	0.002	0.226	0.000	5.544	0.037
EWG1D/2	2/12/88	132	0.000	0.027	0.002	0.171	0.000		
EWG1D/1	2/13/88	129	0.000	0.018	0.000	0.127	0.000	2.981	0.000
EWG1D/2	2/13/88	129	0.000	0.000	0.000	0.104	0.000		
EWG1D/1	2/14/88	115	0.000	0.000	0.000	0.068	0.000	1.874	0.000
EWG1D/2	2/14/88	120	0.000	0.000	0.000	0.088	0.000		
EWG1D/1	2/15/88	155	0.000	0.000	0.000	0.400	0.000	6.699	0.018
EWG1D/2	2/15/88	155	0.000	0.000	0.000	0.158	0.001		
EWG1D/1	2/16/88	125	0.000	0.000	0.000	0.063	0.000	1.680	0.000
EWG1D/2	2/16/88	128	0.000	0.000	0.000	0.077	0.000		
EWG1D/1	2/17/88	98	0.000	0.000	0.000	0.046	0.000	1.198	0.000
EWG1D/2	2/17/88	100	0.000	0.000	0.000	0.054	0.000		

TOTAL Lbs FID VOC 25.713

TOTAL Lbs ECD VOC 0.096

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

(a) Average of two samples collected during the day.

TABLE 6.2 (cont.)

SECOND THROUGH EIGHTH WEEK-COLLECTION ONCE PER DAY

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG1D/1	2/18/88	110	0.000	0.000	0.000	0.048	0.000	1.152	0.013
	2/19/88	108	0.000	0.000	0.000	0.039	0.000	0.932	0.000
	2/20/88	112	0.000	0.000	0.000	0.041	0.000	0.973	0.000
	2/21/88	108	0.000	0.000	0.000	0.038	0.000	0.903	0.011
	2/22/88	97	0.000	0.000	0.000	0.031	0.000	0.755	0.009
	2/23/88	100	0.000	0.000	0.000	0.036	0.000	0.860	0.011
	2/24/88	97	0.000	0.000	0.000	0.095	0.000	2.276	0.000
	2/25/88	101	0.000	0.000	0.000	0.081	0.000	1.955	0.005
	2/26/88	118	0.000	0.000	0.000	0.036	0.000	0.863	0.007
	2/29/88	102	0.000	0.000	0.001	0.055	0.000	1.328	0.036
	3/01/88	106	0.000	0.000	0.000	0.048	0.000	1.154	0.017
	3/02/88	106	0.000	0.000	0.000	0.044	0.001	1.051	0.022
	3/03/88	89	0.000	0.000	0.000	0.033	0.000	0.794	0.003
	3/04/88	107	0.000	0.000	0.000	0.067	0.000	1.610	0.011
	3/05/88	113	0.000	0.000	0.000	0.054	0.000	1.285	0.000
	3/06/88	120	0.000	0.000	0.000	0.046	0.001	1.106	0.020
	3/07/88	106	0.000	0.000	0.000	0.044	0.000	1.052	0.006
	3/08/88	108	0.000	0.000	0.000	0.089	0.001	2.128	0.022
	3/09/88	116	0.000	0.000	0.000	1.158	0.000	27.794	0.014
	3/10/88	121	0.000	0.000	0.000	0.043	0.000	1.028	0.014
	3/11/88	98	0.000	0.000	0.000	0.032	0.000	0.775	0.011

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS; DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.2 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG1D/1	3/18/88	103	0.000	0.029	0.004	0.428	0.001	10.972	0.120
	3/19/88	136	0.000	0.000	0.000	0.072	0.001	1.737	0.023
	3/20/88	109	0.000	0.000	0.000	0.039	0.001	0.942	0.018
	3/21/88	113	0.000	0.000	0.000	0.030	0.000	0.710	0.011
	3/22/88	80	0.000	0.000	0.000	0.020	0.000	0.485	0.008
	3/23/88	116	0.000	0.000	0.000	0.020	0.000	0.479	0.011
	3/24/88	115	0.000	0.000	0.000	0.025	0.000	0.601	0.009
	3/25/88	101	0.000	0.000	0.000	0.019	0.000	0.465	0.009
	3/26/88	109	0.000	0.000	0.000	0.030	0.000	0.713	0.009
	3/27/88	98	0.000	0.000	0.000	0.017	0.000	0.400	0.009
	3/28/88	97	0.000	0.000	0.000	0.012	0.000	0.277	0.006
	3/29/88	96	0.000	0.000	0.000	0.024	0.000	0.582	0.008
	3/30/88	105	0.000	0.000	0.000	0.029	0.000	0.689	0.010
	3/31/88	105	0.000	0.000	0.000	0.029	0.000	0.698	0.012
	4/01/88	119	0.000	0.000	0.000	0.040	0.000	0.959	0.015
	4/02/88	85	0.000	0.000	0.000	0.021	0.000	0.503	0.006
	4/04/88	78	0.000	0.000	0.000	0.021	0.000	0.499	0.007
	4/05/88	105	0.000	0.000	0.000	0.027	0.000	0.641	0.018
	4/06/88	104	0.000	0.000	0.000	0.023	0.000	0.552	0.008
	4/07/88	109	0.000	0.000	0.000	0.018	0.000	0.437	0.008
	4/08/88	111	0.000	0.000	0.000	0.019	0.000	0.456	0.006
	4/09/88	105	0.000	0.000	0.000	0.017	0.000	0.399	0.004
	4/10/88	103	0.000	0.000	0.000	0.014	0.000	0.333	0.005
	4/11/88	104	0.000	0.000	0.000	0.017	0.000	0.401	0.005

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.2 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG1D/1	4/12/88	107	0.000	0.000	0.001	0.013	0.000	0.306	0.025
	4/13/88	119	0.000	0.000	0.000	0.014	0.000	0.341	0.006
	4/14/88	109	0.000	0.000	0.000	0.013	0.000	0.318	0.000
	4/15/88	109	0.000	0.000	0.000	0.016	0.000	0.395	0.000
	4/18/88	109	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TOTAL Lbs FID VOC 78.065

TOTAL Lbs ECD VOC 0.611

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.3 FLOW RATES AND FLUX RATES, EW2S

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG2S/1	2/11/88	62	0.000	0.014	0.001	0.297	0.000	7.465	0.031
	2/12/88	52	0.000	0.007	0.000	0.134	0.001	3.395	0.025
	2/13/88	52	0.000	0.008	0.000	0.157	0.000	3.950	0.000
	2/14/88	32	0.000	0.000	0.000	0.074	0.000	1.786	0.000
	2/15/88	62	0.000	0.000	0.001	0.159	0.000	3.811	0.020
	2/16/88	47	0.000	0.006	0.000	0.154	0.000	3.849	0.014
	2/17/88	28	0.000	0.000	0.000	0.130	0.000	3.124	0.007
	2/18/88	34	0.000	0.000	0.000	0.085	0.000	2.028	0.008
	2/20/88	28	0.000	0.000	0.000	0.048	0.000	1.141	0.007
	2/22/88	43	0.000	0.000	0.000	0.020	0.000	0.480	0.000
	2/24/88	33	0.000	0.006	0.000	0.013	0.000	0.466	0.007
	2/26/88	42	0.000	0.000	0.000	0.051	0.000	1.227	0.002
	3/01/88	57	0.000	0.000	0.000	0.018	0.000	0.440	0.006
	3/03/88	69	0.000	0.000	0.000	0.051	0.000	1.232	0.003
	3/05/88	55	0.000	0.000	0.000	0.048	0.000	1.140	0.000
	3/07/88	55	0.000	0.000	0.000	0.037	0.000	0.885	0.012
	3/09/88	55	0.000	0.000	0.000	0.099	0.000	2.379	0.012
	3/11/88	57	0.000	0.000	0.000	0.067	0.001	1.603	0.026
	3/18/88	52	0.000	0.000	0.000	0.077	0.001	1.839	0.030
	3/19/88	49	0.000	0.000	0.000	0.043	0.001	1.033	0.018
	3/21/88	55	0.000	0.000	0.000	0.046	0.000	1.104	0.012
	3/23/88	59	0.000	0.000	0.000	0.041	0.001	0.972	0.014

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.3 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG2S/1	3/25/88	57	0.000	0.000	0.000	0.043	0.001	1.037	0.015
	3/27/88	48	0.000	0.000	0.000	0.007	0.000	0.175	0.003
	3/29/88	48	0.000	0.000	0.000	0.026	0.000	0.615	0.010
	3/31/88	50	0.000	0.000	0.000	0.029	0.000	0.690	0.006
	4/02/88	55	0.000	0.000	0.000	0.035	0.000	0.849	0.006
	4/05/88	50	0.000	0.000	0.000	0.025	0.000	0.597	0.008
	4/07/88	38	0.000	0.000	0.000	0.015	0.000	0.369	0.001
	4/09/88	39	0.000	0.000	0.000	0.016	0.000	0.392	0.004
	4/11/88	42	0.000	0.000	0.000	0.017	0.000	0.409	0.004
	4/13/88	47	0.000	0.000	0.000	0.018	0.000	0.439	0.005
	4/15/88	39	0.000	0.000	0.000	0.018	0.000	0.431	0.000
	4/18/88	46	0.000	0.000	0.000	0.020	0.000	0.486	0.000

TOTAL Lbs FID VOC 51.841

TOTAL Lbs ECD VOC 0.315

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.4 FLOW RATES AND FLUX RATES, EW2D

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG2D/1	2/11/88	66	0.000	0.025	0.002	0.315	0.001	8.156	0.076
	2/12/88	70	0.000	0.011	0.000	0.105	0.001	2.787	0.022
	2/13/88	83	0.000	0.033	0.000	0.129	0.001	3.877	0.023
	2/14/88	70	0.000	0.023	0.000	0.090	0.001	2.712	0.018
	2/15/88	62	0.000	0.021	0.000	0.172	0.001	4.623	0.032
	2/16/88	72	0.000	0.016	0.000	0.046	0.000	1.499	0.010
	2/17/88	57	0.000	0.016	0.000	0.045	0.000	1.461	0.009
	2/18/88	79	0.000	0.020	0.000	0.054	0.001	1.778	0.015
	2/20/88	62	0.000	0.014	0.000	0.370	0.000	9.204	0.002
	2/22/88	56	0.000	0.011	0.000	0.021	0.000	0.773	0.002
	2/24/88	77	0.000	0.011	0.000	0.025	0.000	0.868	0.014
	2/26/88	62	0.000	0.012	0.000	0.022	0.000	0.817	0.010
	3/01/88	53	0.000	0.011	0.000	0.027	0.001	0.899	0.018
	3/03/88	62	0.000	0.011	0.000	0.024	0.000	0.834	0.011
	3/05/88	76	0.000	0.015	0.000	0.033	0.000	1.146	0.000
	3/07/88	68	0.000	0.014	0.000	0.126	0.000	3.351	0.000
	3/09/88	81	0.000	0.016	0.000	0.057	0.001	1.754	0.026
	3/11/88	81	0.000	0.015	0.000	0.134	0.001	3.569	0.039
	3/18/88	71	0.000	0.015	0.000	0.048	0.001	1.509	0.027
	3/19/88	85	0.000	0.017	0.000	0.034	0.001	1.220	0.019
	3/21/88	101	0.000	0.018	0.000	0.034	0.000	1.238	0.013
	3/23/88	83	0.000	0.014	0.000	0.038	0.001	1.265	0.016

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS; DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.4 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG20/1	3/25/88	93	0.000	0.000	0.000	0.026	0.000	0.626	0.013
	3/27/88	83	0.000	0.014	0.000	0.042	0.001	1.351	0.018
	3/29/88	68	0.000	0.000	0.000	0.021	0.000	0.501	0.009
	3/31/88	72	0.000	0.000	0.000	0.019	0.000	0.462	0.006
	4/02/88	79	0.000	0.000	0.000	0.027	0.000	0.637	0.008
	4/05/88	66	0.000	0.011	0.000	0.029	0.000	0.970	0.010
	4/07/88	94	0.000	0.015	0.000	0.030	0.000	1.087	0.009
	4/09/88	87	0.000	0.014	0.000	0.029	0.000	1.040	0.006
	4/11/88	91	0.000	0.000	0.000	0.029	0.000	0.696	0.005
	4/13/88	101	0.000	0.000	0.000	0.147	0.000	3.520	0.005
	4/15/88	85	0.000	0.000	0.000	0.026	0.000	0.616	0.000
	4/18/88	98	0.000	0.000	0.000	0.022	0.000	0.532	0.000

TOTAL Lbs FID VOC 67.377

TOTAL Lbs ECD VOC 0.494

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.5 FLOW RATES AND FLUX RATES, EW3S

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECO Lbs/DAY
EWG3S/1	2/11/88	31	0.000	0.024	0.007	0.849	0.001	20.946	0.190
	2/12/88	28	0.000	0.016	0.005	0.621	0.001	15.303	0.150
	2/13/88	35	0.000	0.016	0.005	0.647	0.003	15.911	0.197
	2/14/88	28	0.000	0.010	0.003	0.439	0.001	10.784	0.082
	2/15/88	24	0.000	0.009	0.002	0.418	0.001	10.263	0.075
	2/16/88	17	0.000	0.006	0.001	0.270	0.001	6.606	0.029
	2/17/88	14	0.000	0.000	0.000	0.045	0.000	1.082	0.007
	2/18/88	17	0.000	0.000	0.000	0.074	0.000	1.770	0.012
	2/20/88	14	0.000	0.000	0.000	0.060	0.000	1.435	0.006
	2/22/88	22	0.000	0.004	0.001	0.220	0.001	5.388	0.032
	2/24/88	22	0.000	0.003	0.000	0.194	0.001	4.747	0.029
	2/26/88	21	0.000	0.003	0.000	0.183	0.000	4.466	0.009
	3/01/88	28	0.000	0.004	0.000	0.269	0.001	6.568	0.033
	3/03/88	27	0.000	0.004	0.000	0.206	0.001	5.043	0.040
	3/05/88	35	0.000	0.005	0.000	0.260	0.001	6.377	0.023
	3/07/88	28	0.000	0.000	0.000	0.134	0.001	3.228	0.022
	3/09/88	24	0.000	0.004	0.000	0.183	0.001	4.494	0.034
	3/11/88	28	0.000	0.000	0.000	0.120	0.001	2.884	0.021
	3/18/88	26	0.000	0.005	0.000	0.256	0.002	6.284	0.059
	3/19/88	25	0.000	0.000	0.000	0.162	0.002	3.883	0.045
	3/21/88	29	0.000	0.000	0.000	0.131	0.001	3.145	0.028
	3/23/88	28	0.000	0.000	0.000	0.131	0.001	3.146	0.033

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECO ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.5 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG3S/1	3/25/88	25	0.000	0.000	0.000	0.108	0.001	2.601	0.025
	3/27/88	20	0.000	0.000	0.000	0.145	0.002	3.476	0.042
	3/29/88	27	0.000	0.000	0.000	0.179	0.002	4.287	0.054
	3/31/88	27	0.000	0.000	0.000	0.123	0.001	2.942	0.027
	4/02/88	21	0.000	0.000	0.000	0.083	0.001	1.991	0.014
	4/05/88	29	0.000	0.000	0.000	0.157	0.001	3.758	0.038
	4/07/88	23	0.000	0.000	0.000	0.074	0.001	1.783	0.018
	4/09/88	22	0.000	0.000	0.000	0.097	0.001	2.326	0.014
	4/11/88	19	0.000	0.000	0.000	0.034	0.000	0.805	0.005
	4/13/88	19	0.000	0.000	0.000	0.027	0.000	0.655	0.011
	4/15/88	19	0.000	0.000	0.000	0.043	0.000	1.031	0.000
	4/18/88	19	0.000	0.000	0.000	0.034	0.000	0.812	0.000

TOTAL Lbs FID VOC 170.222

TOTAL Lbs ECD VOC 1.404

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** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.6 FLOW RATES AND FLUX RATES, EW3D

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG3D/1	2/11/88	39	0.000	0.038	0.006	0.493	0.001	12.744	0.173
	2/12/88	37	0.000	0.036	0.003	0.268	0.002	7.302	0.104
	2/13/88	22	0.000	0.028	0.003	0.171	0.001	4.773	0.082
	2/14/88	19	0.000	0.018	0.001	0.149	0.001	3.996	0.058
	2/15/88	24	0.000	0.016	0.002	0.159	0.001	4.191	0.082
	2/16/88	30	0.000	0.016	0.001	0.172	0.002	4.510	0.060
	2/17/88	19	0.000	0.008	0.001	0.092	0.001	2.409	0.035
	2/18/88	28	0.000	0.010	0.000	0.108	0.001	2.822	0.031
	2/20/88	23	0.000	0.006	0.006	0.057	0.000	1.513	0.145
	2/22/88	19	0.000	0.004	0.000	0.032	0.000	0.863	0.010
	2/24/88	23	0.000	0.004	0.000	0.048	0.000	1.233	0.007
	2/26/88	19	0.000	0.003	0.000	0.023	0.000	0.623	0.007
	3/01/88	21	0.000	0.004	0.000	0.015	0.000	0.458	0.017
	3/03/88	20	0.000	0.005	0.000	0.036	0.001	0.988	0.030
	3/05/88	15	0.000	0.005	0.000	0.025	0.000	0.734	0.004
	3/07/88	19	0.000	0.003	0.000	0.032	0.000	0.849	0.009
	3/09/88	24	0.000	0.006	0.000	0.063	0.001	1.647	0.022
	3/11/88	15	0.000	0.003	0.000	0.060	0.000	1.518	0.011
	3/18/88	32	0.000	0.009	0.002	0.106	0.000	2.760	0.038
	3/19/88	32	0.000	0.007	0.000	0.059	0.001	1.596	0.030
	3/21/88	19	0.000	0.004	0.000	0.045	0.000	1.175	0.014
	3/23/88	19	0.000	0.003	0.000	0.039	0.000	1.014	0.006

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.6 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG30/1	3/25/88	24	0.000	0.000	0.001	0.035	0.001	0.846	0.047
	3/27/88	27	0.000	0.005	0.000	0.058	0.001	1.516	0.026
	3/29/88	19	0.000	0.003	0.000	0.037	0.001	0.959	0.015
	3/31/88	18	0.000	0.000	0.000	0.024	0.000	0.575	0.011
	4/02/88	7	0.000	0.001	0.000	0.012	0.000	0.313	0.004
	4/05/88	7	0.000	0.001	0.000	0.013	0.000	0.354	0.005
	4/07/88	14	0.000	0.003	0.000	0.025	0.000	0.664	0.009
	4/09/88	14	0.000	0.003	0.000	0.023	0.000	0.616	0.008
	4/11/88	14	0.000	0.002	0.000	0.023	0.000	0.610	0.007
	4/13/88	14	0.000	0.000	0.000	0.017	0.000	0.412	0.002
	4/15/88	14	0.000	0.000	0.000	0.019	0.000	0.460	0.000
	4/18/88	14	0.000	0.000	0.000	0.018	0.000	0.435	0.000

TOTAL Lbs FID VOC 67.476

TOTAL Lbs ECD VOC 1.105

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.7 FLOW RATES AND FLUX RATES, EW4S

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG4S/1	2/11/88	24	0.000	0.045	0.005	0.999	0.002	25.073	0.175
	2/12/88	28	0.000	0.034	0.005	0.929	0.002	23.114	0.171
	2/13/88	35	0.000	0.032	0.006	0.979	0.002	24.272	0.179
	2/14/88	28	0.000	0.031	0.006	1.198	0.004	29.507	0.221
	2/15/88	28	0.000	0.025	0.005	0.941	0.003	23.194	0.186
	2/16/88	23	0.000	0.022	0.002	0.842	0.001	20.736	0.090
	2/17/88	25	0.000	0.026	0.003	0.932	0.002	22.995	0.120
	2/18/88	25	0.000	0.026	0.003	0.932	0.003	22.985	0.140
	2/20/88	21	0.000	0.021	0.002	0.821	0.003	20.199	0.123
	2/22/88	25	0.000	0.018	0.002	0.797	0.002	19.563	0.111
	2/24/88	25	0.000	0.018	0.002	0.866	0.003	21.218	0.135
	2/26/88	28	0.000	0.017	0.001	0.785	0.002	19.256	0.073
	3/01/88	32	0.000	0.023	0.003	1.091	0.000	26.727	0.078
	3/03/88	34	0.000	0.015	0.004	0.729	0.008	17.865	0.273
	3/05/88	35	0.000	0.023	0.001	1.079	0.001	26.467	0.066
	3/07/88	34	0.000	0.019	0.001	0.862	0.002	21.146	0.083
	3/09/88	31	0.000	0.022	0.002	0.905	0.003	22.232	0.111
	3/11/88	35	0.000	0.023	0.002	0.993	0.003	24.396	0.126
	3/18/88	30	0.000	0.029	0.002	1.120	0.005	27.585	0.183
	3/19/88	32	0.000	0.027	0.002	1.017	0.006	25.056	0.196
	3/21/88	35	0.000	0.022	0.002	0.784	0.003	19.358	0.102
	3/23/88	34	0.000	0.022	0.001	0.847	0.004	20.846	0.137

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.7 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG4S/1	3/25/88	35	0.000	0.021	0.002	0.872	0.005	21.451	0.168
	3/27/88	27	0.000	0.019	0.002	0.779	0.005	19.136	0.167
	3/29/88	27	0.000	0.017	0.001	0.745	0.004	18.289	0.115
	3/31/88	30	0.000	0.012	0.001	0.670	0.003	16.372	0.106
	4/02/88	34	0.000	0.014	0.001	0.735	0.003	17.981	0.085
	4/05/88	36	0.000	0.019	0.002	0.820	0.004	20.123	0.144
	4/07/88	38	0.000	0.019	0.002	0.839	0.004	20.595	0.125
	4/09/88	30	0.000	0.015	0.001	0.601	0.003	14.779	0.093
	4/11/88	30	0.000	0.013	0.001	0.519	0.002	12.765	0.067
	4/13/88	29	0.000	0.010	0.001	0.376	0.001	9.274	0.062
	4/15/88	31	0.000	0.015	0.000	0.568	0.000	13.999	0.000
	4/18/88	30	0.000	0.015	0.000	0.580	0.000	14.275	0.000

TOTAL Lbs FID VOC 702.830

TOTAL Lbs ECD VOC 4.214

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS; DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.8 FLOW RATES AND FLUX RATES, EW4D

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG4D/1	2/11/88	32	0.000	0.036	0.004	0.228	0.001	6.339	0.131
	2/12/88	40	0.000	0.066	0.008	0.457	0.003	12.555	0.256
	2/13/88	28	0.000	0.030	0.005	0.274	0.001	7.286	0.153
	2/14/88	26	0.000	0.023	0.004	0.300	0.003	7.753	0.157
	2/15/88	23	0.000	0.011	0.001	0.142	0.001	3.663	0.056
	2/16/88	30	0.000	0.018	0.002	0.244	0.002	6.268	0.088
	2/17/88	35	0.000	0.018	0.002	0.244	0.003	6.287	0.101
	2/18/88	30	0.000	0.013	0.001	0.163	0.001	4.212	0.061
	2/20/88	24	0.000	0.008	0.001	0.107	0.002	2.771	0.058
	2/22/88	19	0.000	0.003	0.000	0.040	0.000	1.021	0.010
	2/24/88	21	0.000	0.005	0.000	0.172	0.001	4.252	0.036
	2/26/88	19	0.000	0.004	0.000	0.046	0.001	1.207	0.019
	3/01/88	15	0.000	0.005	0.000	0.042	0.000	1.114	0.010
	3/03/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/05/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/07/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/09/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/11/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/15/88	4	0.000	0.001	0.000	0.012	0.000	0.319	0.009
	3/19/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/21/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/23/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

TABLE 6.8 (cont.)

SAMPLE CODE	DATE	FLOW SCFM	MeCl** Lbs/hr	DCE Lbs/hr	TRI ** Lbs/hr	TCE Lbs/hr	PCE ** Lbs/hr	TOTAL FID Lbs/DAY	TOTAL ECD Lbs/DAY
EWG40/1	3/25/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/27/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/29/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3/31/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	4/02/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	4/05/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	4/07/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	4/09/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	4/11/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	4/13/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	4/15/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	4/18/88	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TOTAL Lbs FID VOC 65.047

TOTAL Lbs ECD VOC 1.142

** RESULTS OF MeCl, TRI, & PCE ARE FROM ECD ANALYSIS: DCE & TCE RESULTS ARE FROM FID ANALYSIS

origin (0,0). Each collection point has an x and y coordinate, and TCE concentrations are plotted on a "Z" scale, which gives a three-dimensional plot across the grid. Values of "Z" between data points and around the grid are generated by the Kriging technique, which uses given data points and a regional variable theory to generate values between and around sample locations. Kriging is the name given to the least squares prediction of spatial processes and is used in surface fitting, trend surface analysis, and contouring of sparse spatial data.

A total of twelve shallow punch bar tubes were utilized along with the four shallow vacuum monitoring wells. The punch bars were driven to a depth of 3 to 5 ft, and as with the vacuum wells, soil gas was drawn up the punch bar probes with a low volume personal pump and tygon tubing. 50-ml gas-tight syringes were used to collect the sample out of the tygon tubing. The gas samples were analyzed in the field trailer using gas chromatographs with flame ionization detectors and electron capture detectors.

The soil gas results show a considerable reduction in concentration over the course of the 56-day demonstration period as can be seen from Figures 6.1, 6.2, and 6.3. This is to be expected since soil gas is the vapor halo existing around the contamination and should be relatively easy to remove by vacuum methods.

A more modest reduction can be seen in the results obtained for soil VOC concentrations by GC/MS purge-and-trap analytical techniques. Soil concentrations include not only the vapor halo but also interstitial liquid contamination that is either dissolved in the moisture in the soil or existing as a two phase liquid with the moisture.

Table 6.9 shows the reduction of the weighted average TCE levels in the soil during the course of the 56-day demonstration test. The weighted average TCE level was obtained by averaging soil concentrations obtained every two feet by split spoon sampling methods over the entire 24-foot depth of the wells. The largest reduction in soil TCE concentration occurred in extraction well 4, which had the highest initial level of contamination. The majority of the soil borings taken after the test showed VOC levels that were not detectable. Extraction well 1, which was expected to have the greatest concentration reduction potential, exhibited only a minor decrease over the course of the test. Undoubtedly this was because of the greater-than-expected level of contamination that existed in the area around monitoring well 3 that was drawn into the soil around extraction well 1. The decrease in the TCE level around monitoring well 3 tends to bear this out.

The TCLP or Toxic Characteristic Leaching Procedure tests provides another tool by which this technology could be evaluated. This test is designed to determine the potential for the leaching of, in this case, volatile organic constituent, into ground water. Samples were extracted, using a zero headspace extraction (ZHE) vessel, by an extraction fluid consisting of an aqueous solution of glacial acetic acid.

The results of TCLP sampling and analysis program were of limited use in the evaluation of the technology. Most of the pretreatment TCLP samples were not analyzed within the required holding time periods. The midtreatment and posttreatment samples were extracted and analyzed properly, but the data

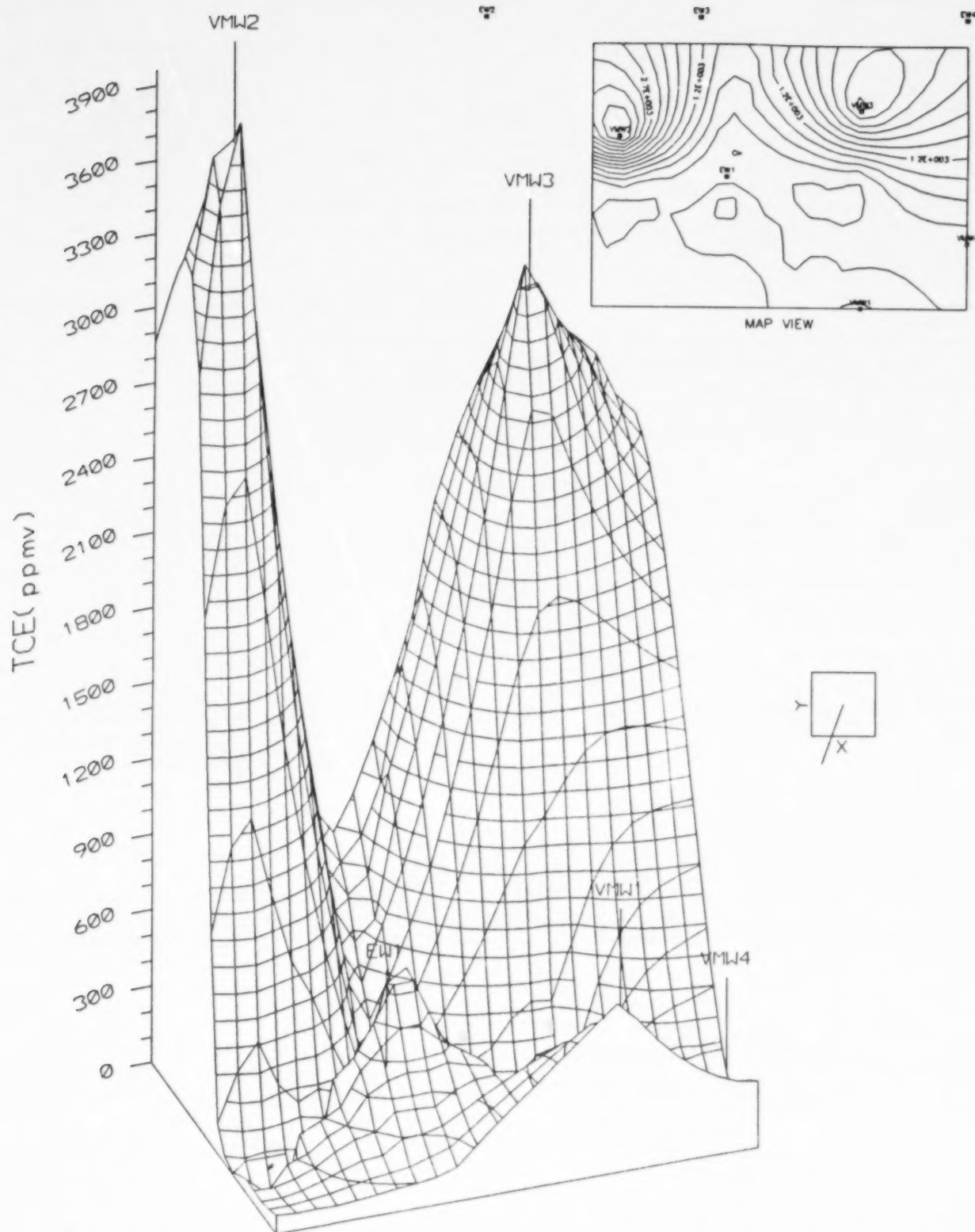


Figure 6.1. Pretreatment shallow soil gas concentration.

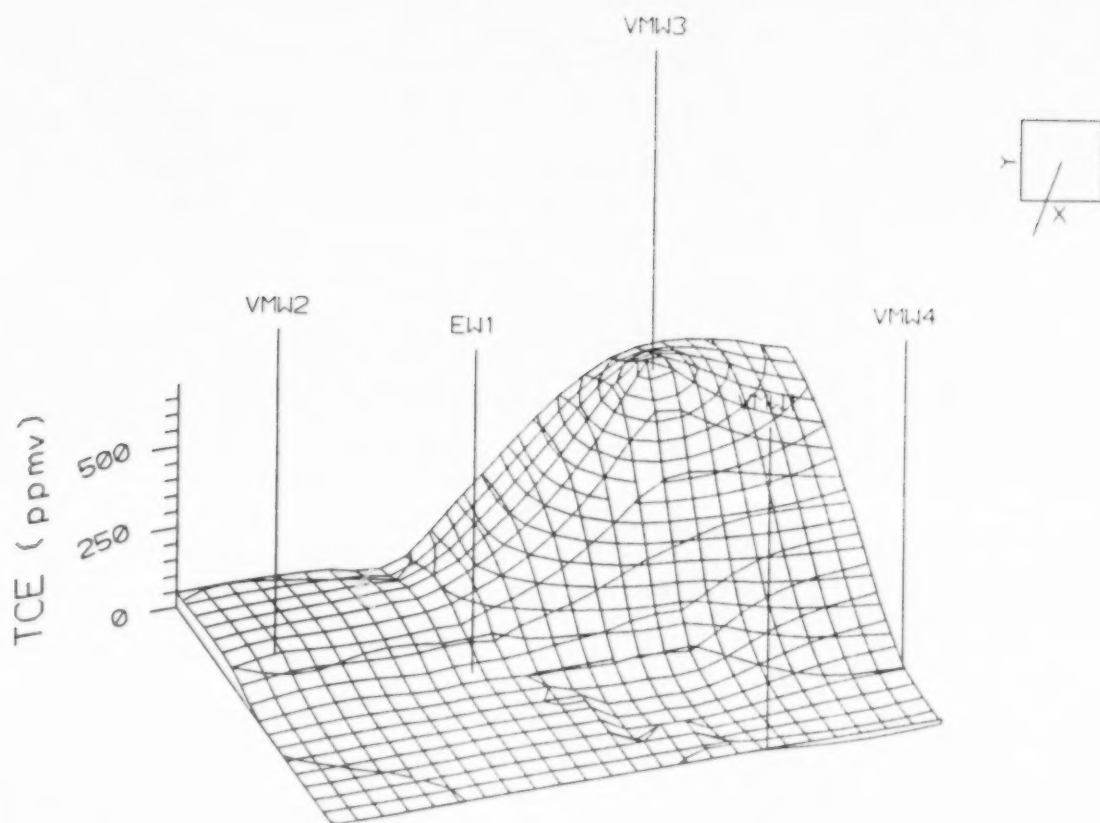


Figure 6.2. Midtreatment shallow soil gas concentration.

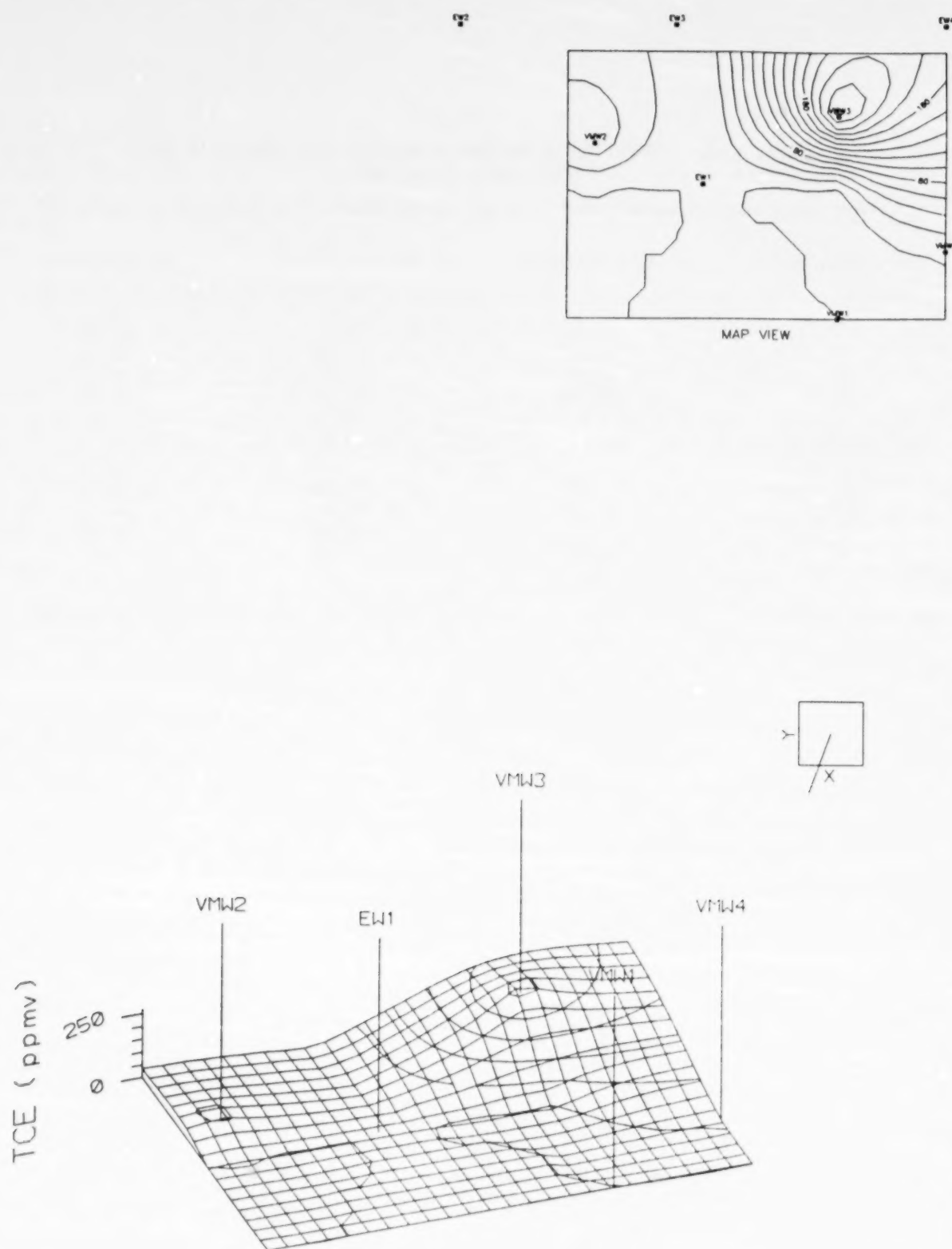


Figure 6.3. Posttreatment shallow soil gas concentration.

TABLE 6.9. REDUCTION OF WEIGHTED AVERAGE TCE LEVELS IN SOIL
(TCE Conc. in mg/kg)

Extraction Well	Pretreatment	Posttreatment	% Reduction
1	33.98	29.31	13.74
2	3.38	2.36	30.18
3	6.89	6.30	8.56
4	96.10	4.19	95.64
Monitoring Well			
1	1.10	0.34	69.09
2	14.75	8.98	39.12
3	227.31	84.50	62.83
4	0.87	1.05	-

obtained were of limited use, because of the large number of nondetect values obtained.

6.3 EFFECTIVENESS OF THE TECHNOLOGY IN VARIOUS SOIL TYPES

The soil strata at the Groveland site can be characterized generally as consisting of the following types in order of increasing depth to groundwater:

- o medium to very fine silty sands
- o stiff and wet clays
- o sand and gravel

Soil porosity, which is the percentage of total soil volume occupied by pores, was relatively the same for both the clays and the sands. Typically porosity, over the 24-ft depth of the wells, would range between 40% and 50%. Permeabilities, or more accurately hydraulic conductivities, ranged from 10^{-4} cm/sec for the sands to 10^{-8} cm/sec for the clays with corresponding grain sizes equal to 10^{-1} mm to 10^{-3} mm.

Pretest soil boring analyses indicated in general that most of the contamination was in the strata above the clay lens with a considerable quantity perched on top of the clay lens. This was the case for extraction well 4, which showed an excellent reduction of TCE concentration in the medium to fine sandy soils existing above the clay layer, with no TCE detected in the clay in either the pretest or posttest borings (see Table 6.10). One of the wells, however, was an exception. This was monitoring well 3, which contained the highest contamination levels of any of the wells, and was exceptional in that most of the contamination was in a wet clay stratum. The levels of contamination were in the 200-1600 ppm range before the test.

After the test, analyses of the soil boring adjacent to monitoring well 3 showed levels in the range of ND-60 ppm in the same clay stratum. The data suggest that the technology can desorb or otherwise mobilize VOCs out of certain clays (see Table 6.11).

From the results of this demonstration it appears that the permeability of a soil need not be a consideration in applying the vacuum extraction technology. This may be explained by the fact that the porosities were approximately the same for all soil strata, so that the total flow area for stripping air was the same in all soil strata. It will take a long time for a liquid contaminant to percolate through clay with its small pore size and consequent low permeability. However, the much smaller air molecules have a lower resistance in passing through the same pores. This may explain why contamination was generally not present in the clay strata but when it was, it was not difficult to remove. Further testing should be done in order to confirm this finding.

6.4 CORRELATION OF DECLINING VOC RECOVERY RATES

The vacuum extraction of volatile organic constituents from the soil may be viewed as an unsteady state process taking place in a nonhomogeneous environment acted upon by the combined convective forces of induced stripping air and by the vacuum assisted volatilization and diffusion of volatiles from a

TABLE 6.10. EXTRACTION WELL 4
TCE REDUCTION IN SOIL STRATA

Depth ft	Description of strata	Permeability cm/sec	TCE Conc. ppm pre post
0-2	Med. sand w/gravel	10 ⁻⁴	2.94 ND
2-4	Lt. brown fine sand	10 ⁻⁴	29.90 ND
4-6	Med. stiff lt. brown fine sand	10 ⁻⁵	260.0 39
6-8	Soft dk. brown fine sand	10 ⁻⁵	303.0 9
8-10	Med. stiff brown sand	10 ⁻⁴	351.0 ND
10-12	V stiff lt. brown med. sand	10 ⁻⁴	195.0 ND
12-14	V stiff brown fine sand w/silt	10 ⁻⁴	3.14 2.3
14-16	M stiff grn-brn clay w/silt	10 ⁻⁸	ND ND
16-18	Soft wet clay	10 ⁻⁸	ND ND
18-20	Soft wet clay	10 ⁻⁸	ND ND
20-22	V stiff brn med-coarse sand	10 ⁻⁴	ND ND
22-24	V stiff brn med-coarse w/gravel	10 ⁻³	6.71 ND

TABLE 6.11. MONITORING WELL 3
TCE REDUCTION IN SOIL STRATA

Depth ft	Description of strata	Permeability cm/sec	TCE Conc. ppm pre post
0-2	M. stiff brn. fine sand	10 ⁻⁵	10.30 ND
2-4	M. stiff grey fine sand	10 ⁻⁵	8.33 800
4-6	Soft lt. brn. fine sand	10 ⁻⁴	80.0 84
6-8	Lt. brn. fine sand	10 ⁻⁴	160.0 ND
8-10	Stiff V. fine brn. silty sand	10 ⁻⁴	ND 63
10-12			NR 2.3
12-14	Soft brown silt	10 ⁻⁴	316.0 ND
14-16	Wet green-brown silty clay	10 ⁻⁸	195.0 ND
16-18	Wet green-brown silty clay	10 ⁻⁸	218.0 62
18-20	Wet green-brown silty clay	10 ⁻⁸	1570.0 2.4
20-22	Silt, gravel, and rock frag.	10 ⁻⁴	106.0 ND
22-24	M. stiff lt. brn. med. sand	10 ⁻⁴	64.1 ND

dissolved or sorbed state. As such it is a very complicated process, even though the equipment required to operate the process is very simple.

Classical unsteady state diffusion processes can be graphically represented by plotting the logarithm of the rate of diffusion versus time. Although the representation of the vacuum extraction process presented here might be somewhat simplistic, the correlation obtained by plotting the logarithm of the concentration of contaminant in the wellhead gas versus time and obtaining a least squares best fit line was reasonably good. This type of plot, shown in Figures 6.4 to 6.19, represents the data very well and is more valid than both a linear graph or one plotting concentration versus log time, in which a best fit curve would actually predict gas concentrations of zero or less.

Looking at the plots for extraction well 1, shallow and deep, equations are given for the least squares best fit line for the data points. If the vacuum extraction process is run long enough so that the detection limit for TCE on the ECD is reached, which is 1 ppbv, the length of time required to reach that concentration would be 239 days on the shallow well and 272 days on the deep well, not unreasonable lengths of time to be running on an in situ treatment process for the remediation of a site.

6.5 PREDICTION OF TIME REQUIRED FOR SITE REMEDIATION

Table 6.12 compares wellhead gas TCE concentration with TCE concentration in the soil, arrived at by weight averaging the concentrations over the screened depth of each well. In the case of extraction well 4, the concentrations were averaged over the depth of the shallow section only, since the deep section became silted up and subsequently no extraction took place from the deep section after almost four weeks of operation.

The soil concentration that would be calculated from the wellhead gas concentration using Henry's Law is included in the last column of Table 6.12. Calculations for the predicted soil concentrations were made assuming a bulk density of the soil of 1761 kg/m^3 , a total porosity of 50% and a moisture content of 20%. The calculated air filled porosity of the soil is approximately 15%. Henry's constant was taken to be $0.492 \text{ KPa/m}^3\text{-gmol}$ at 40°F .

TCE concentrations in the soil calculated by use of empirically derived Henry's constants for aqueous systems, with the exception of well 4S, are not in good agreement with the data obtained. This is undoubtedly due both to interactions of TCE with organic matter in the soil and to inhomogeneities of the contamination distribution in the subsurface.

As was explained previously, the area around extraction well 1 was the area targeted by the design of the system to get as clean as possible during the demonstration time period. A remediation level of 50 ppb in the soil may be used. This concentration is approximately one order of magnitude lower than that calculated by using an EPA revised Organic Leachate Model in conjunction with a Vertical and Horizontal Spread (VHS) model (EPA Draft Guidelines for Petitioning Waste Generated by the Petroleum Refinery Industry) which predicts soil concentrations from leachate concentrations that have been derived from maximum compliance point concentrations based on regulatory standards for drinking water.

TABLE 6.12. COMPARISON OF WELLHEAD GAS VOC
CONCENTRATION AND SOIL VOC CONCENTRATION

Extraction Well	TCE Concentration in Wellhead Gas ppmv	TCE Concentration in soil ppmw	Predicted by Henry's Law ppmw
1S	9.7	54.5	0.11
1D	5.6	7.2	0.07
2S	16.4	ND	0.20
2D	14.4	20.4	0.17
3S	125.0	20.9	1.53
3D	58.7	18.0	0.74
4S	1095.6	9.1	12.49

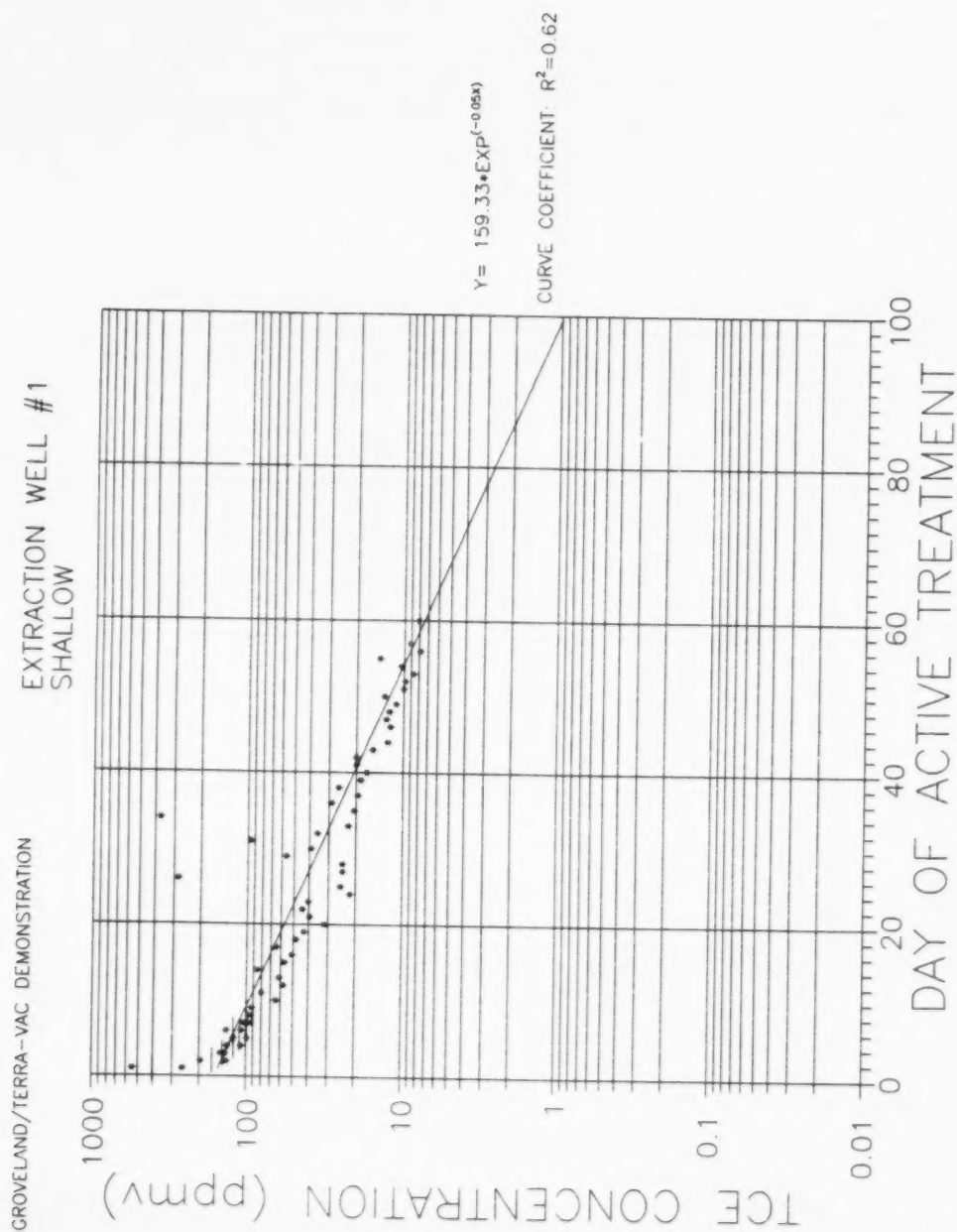


Figure 6.4. Wellhead TCE concentration vs time.

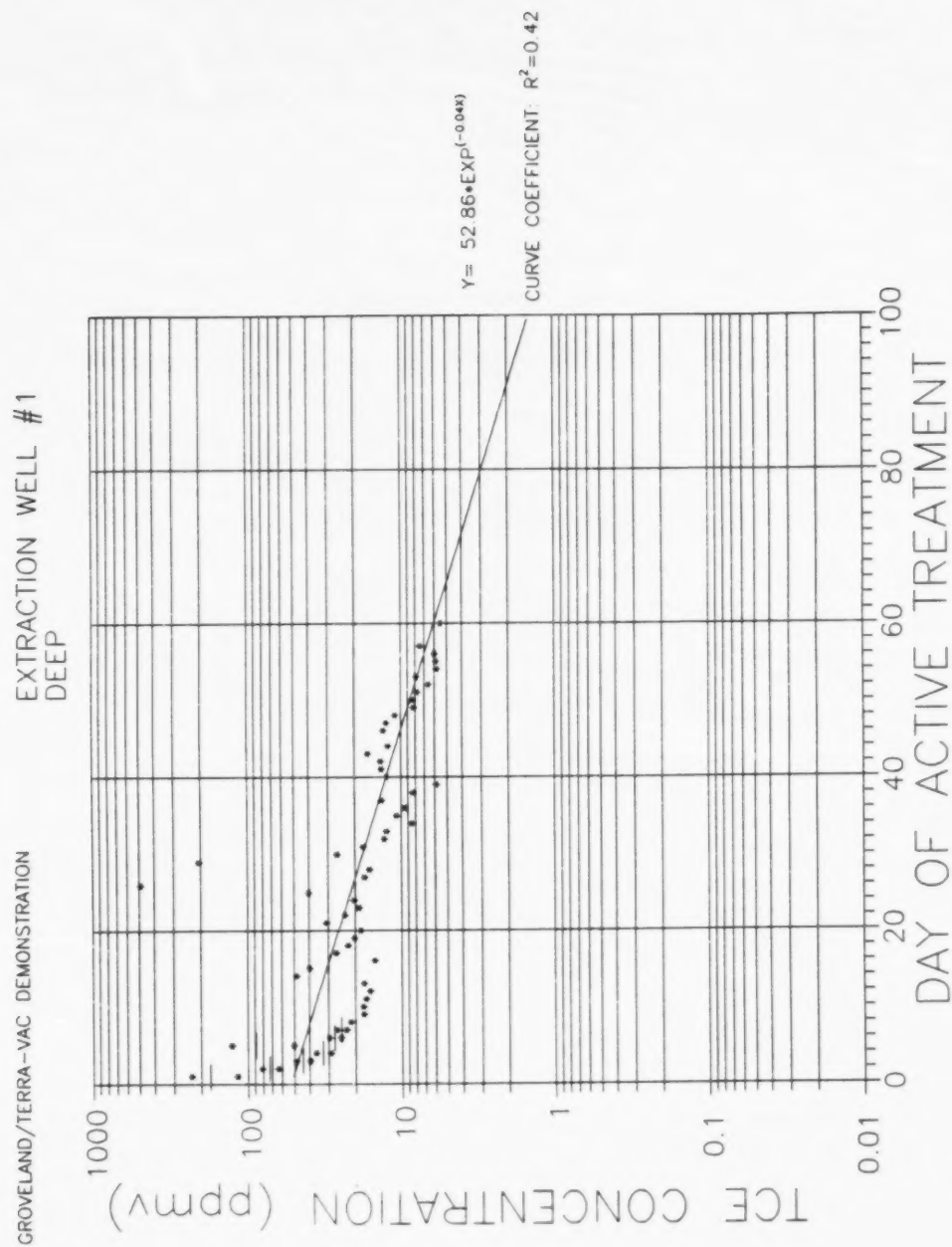


Figure 6.5. Wellhead TCE concentration vs time.

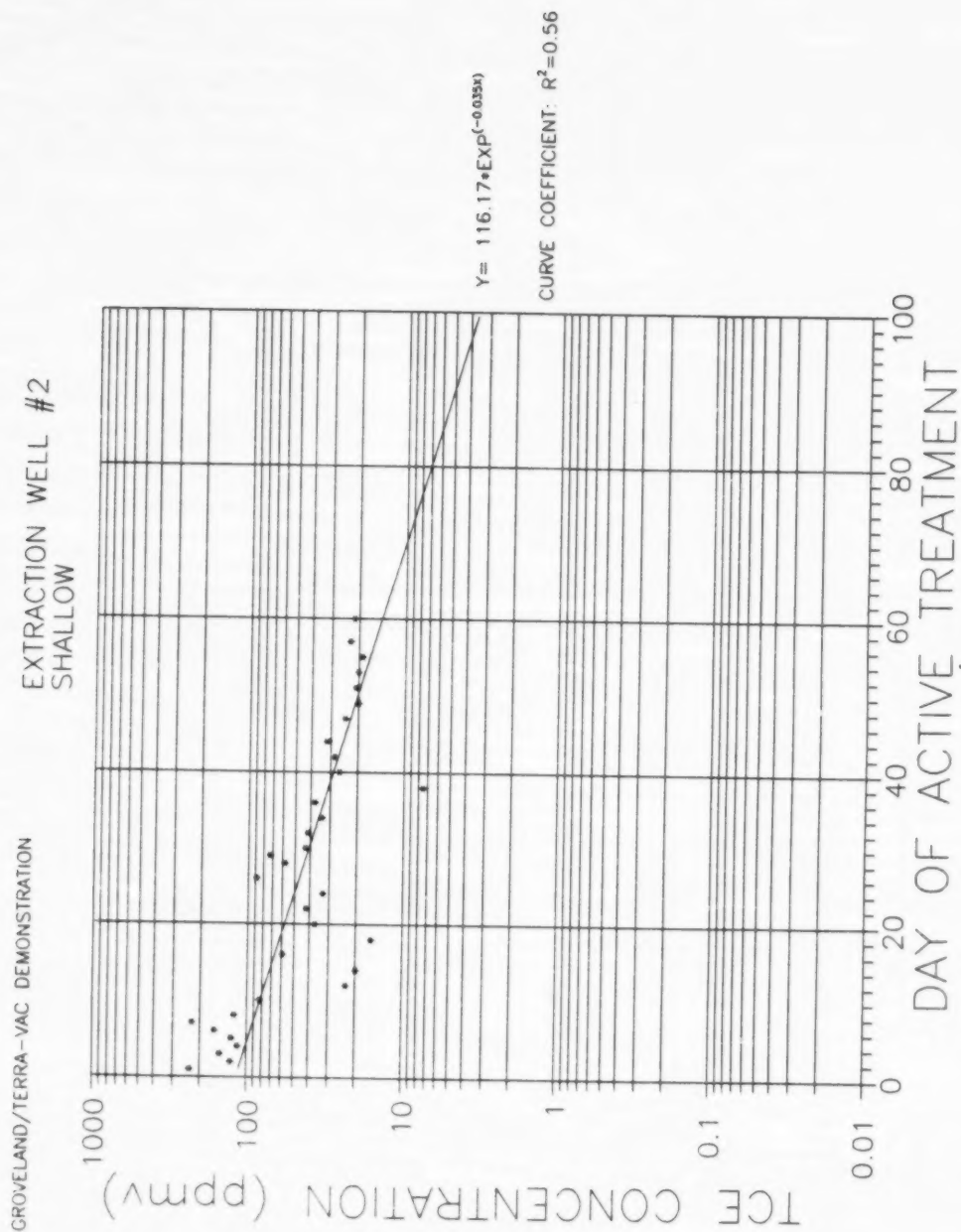


Figure 6.6. Wellhead TCE concentration vs time.

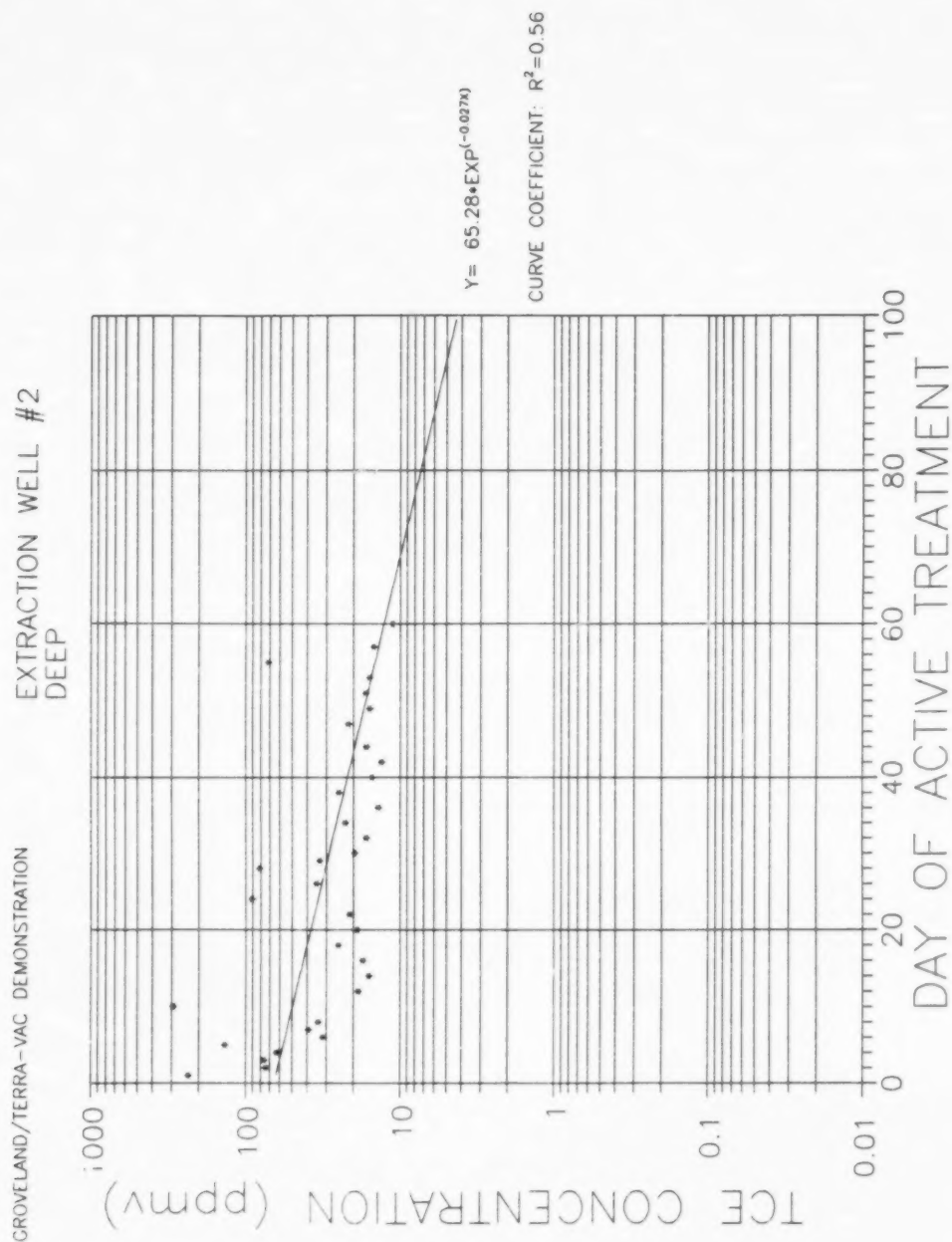


Figure 6.7. Wellhead TCE concentration vs time.

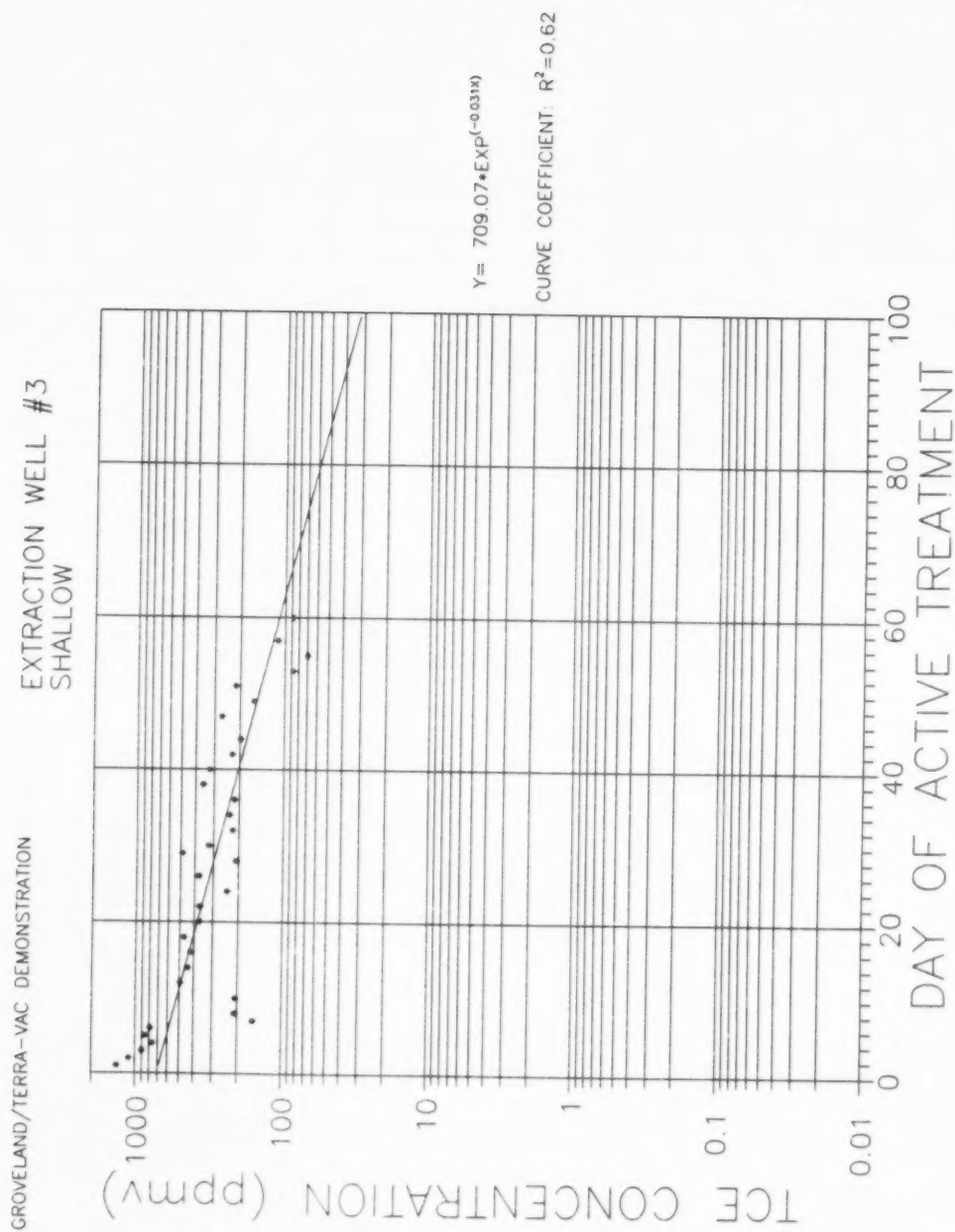


Figure 6.8. Wellhead TCE concentration vs time.

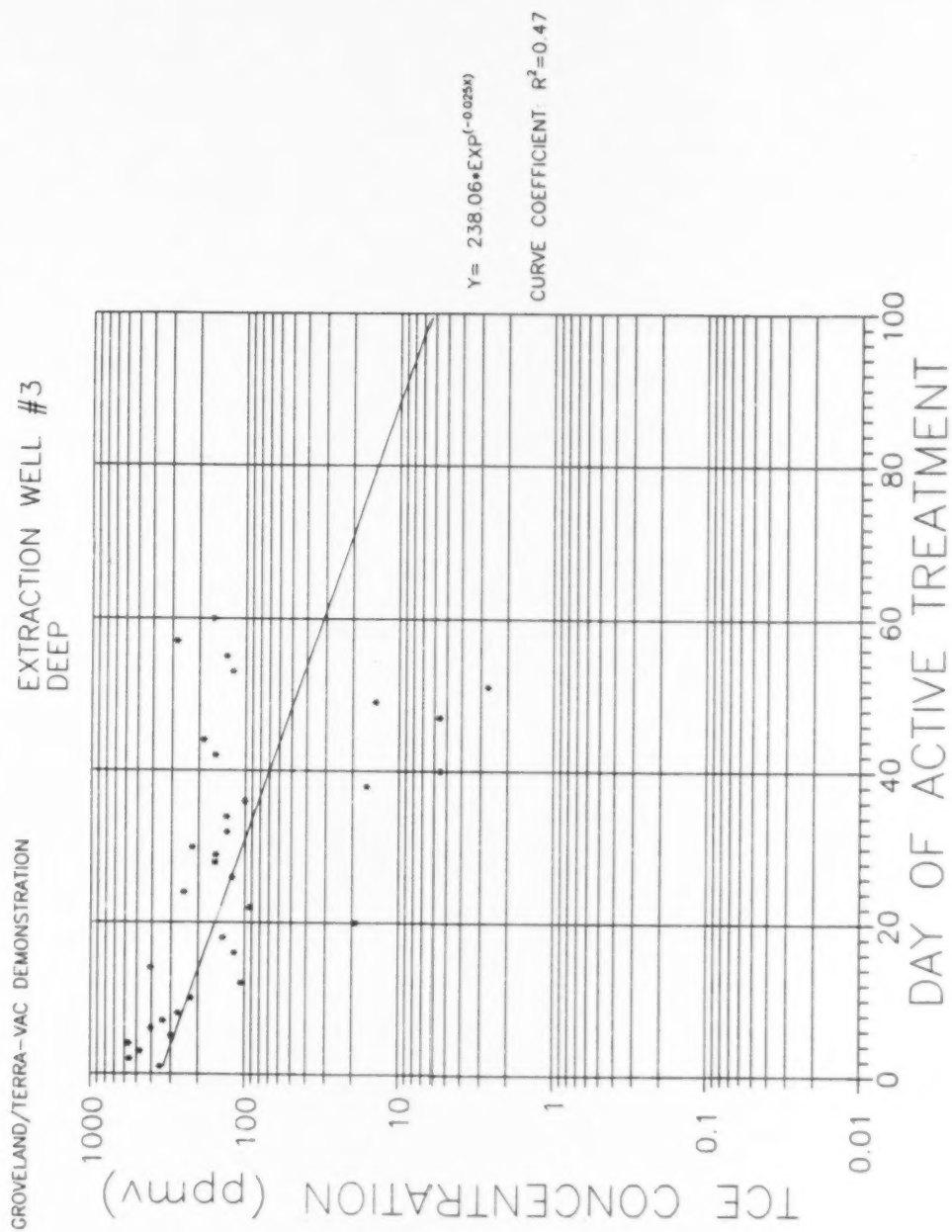


Figure 6.9. Wellhead TCE concentration vs time.

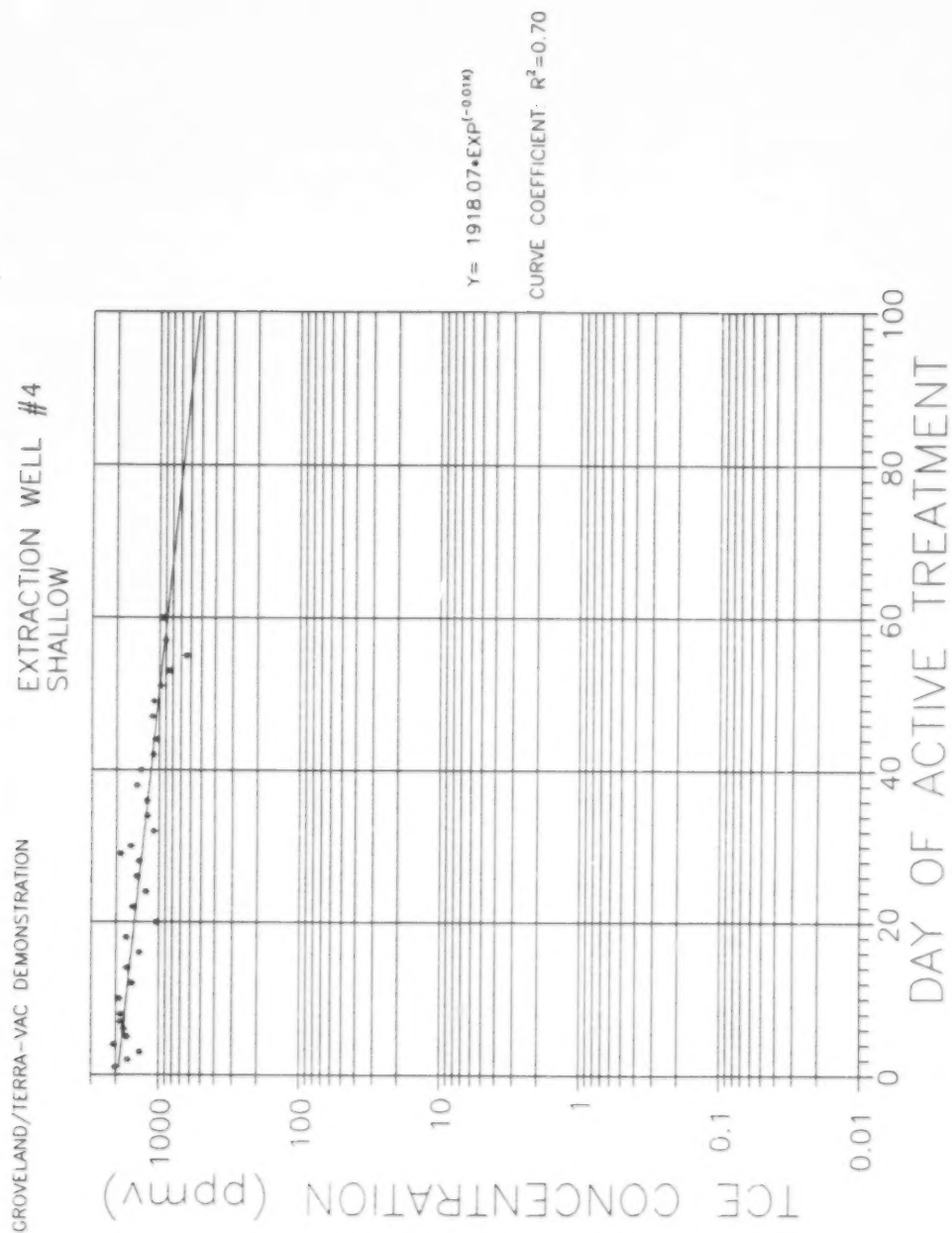


Figure 6.10. Wellhead TCE concentration vs time.

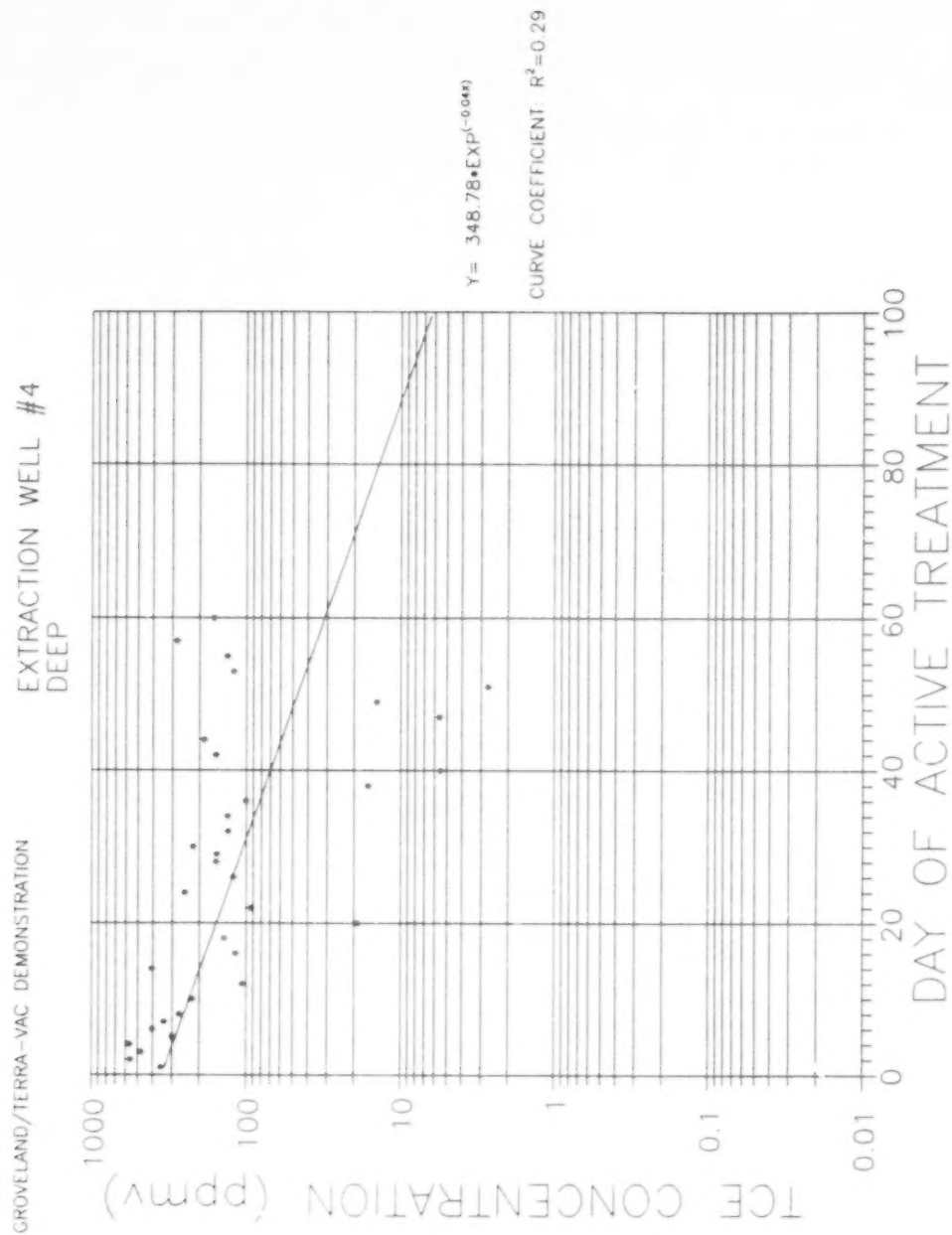


Figure 6.11. Wellhead TCE concentration vs time.

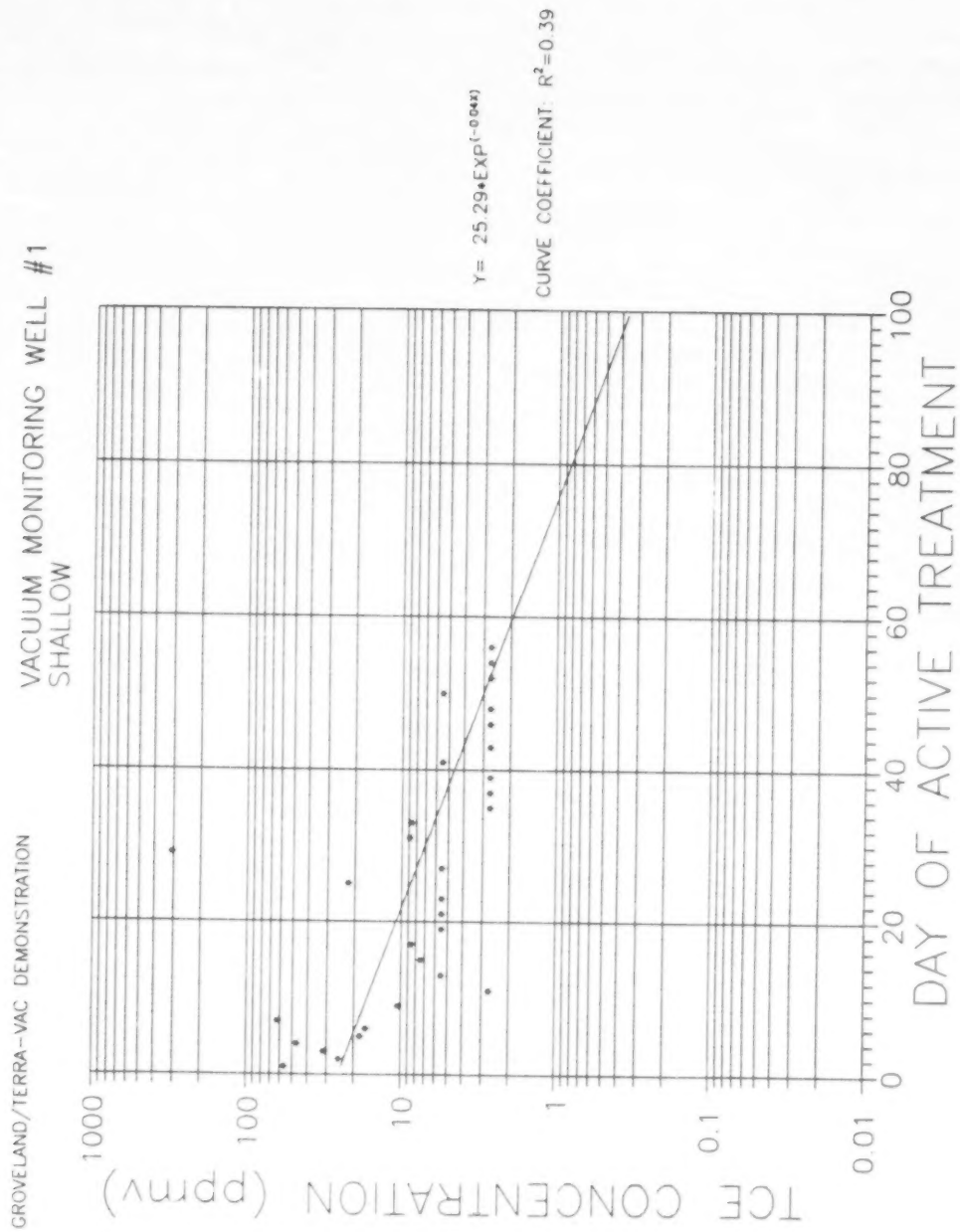


Figure 6.12. Wellhead TCE concentration vs time.



Figure 6.13. Wellhead TCE concentration vs time.

GROVELAND/TERRA-VAC DEMONSTRATION

VACUUM MONITORING WELL #2
SHALLOW

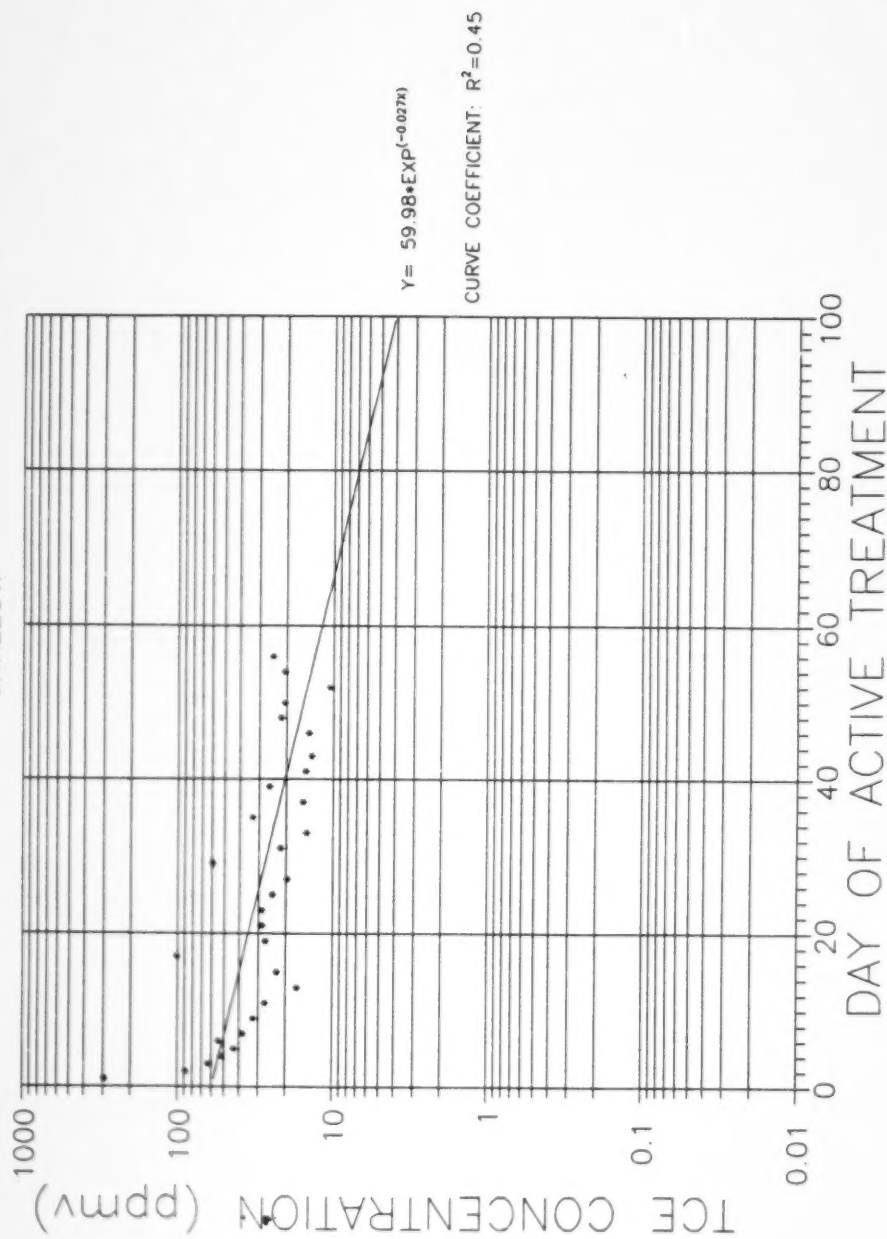


Figure 6.14. Wellhead TCE concentration vs time.

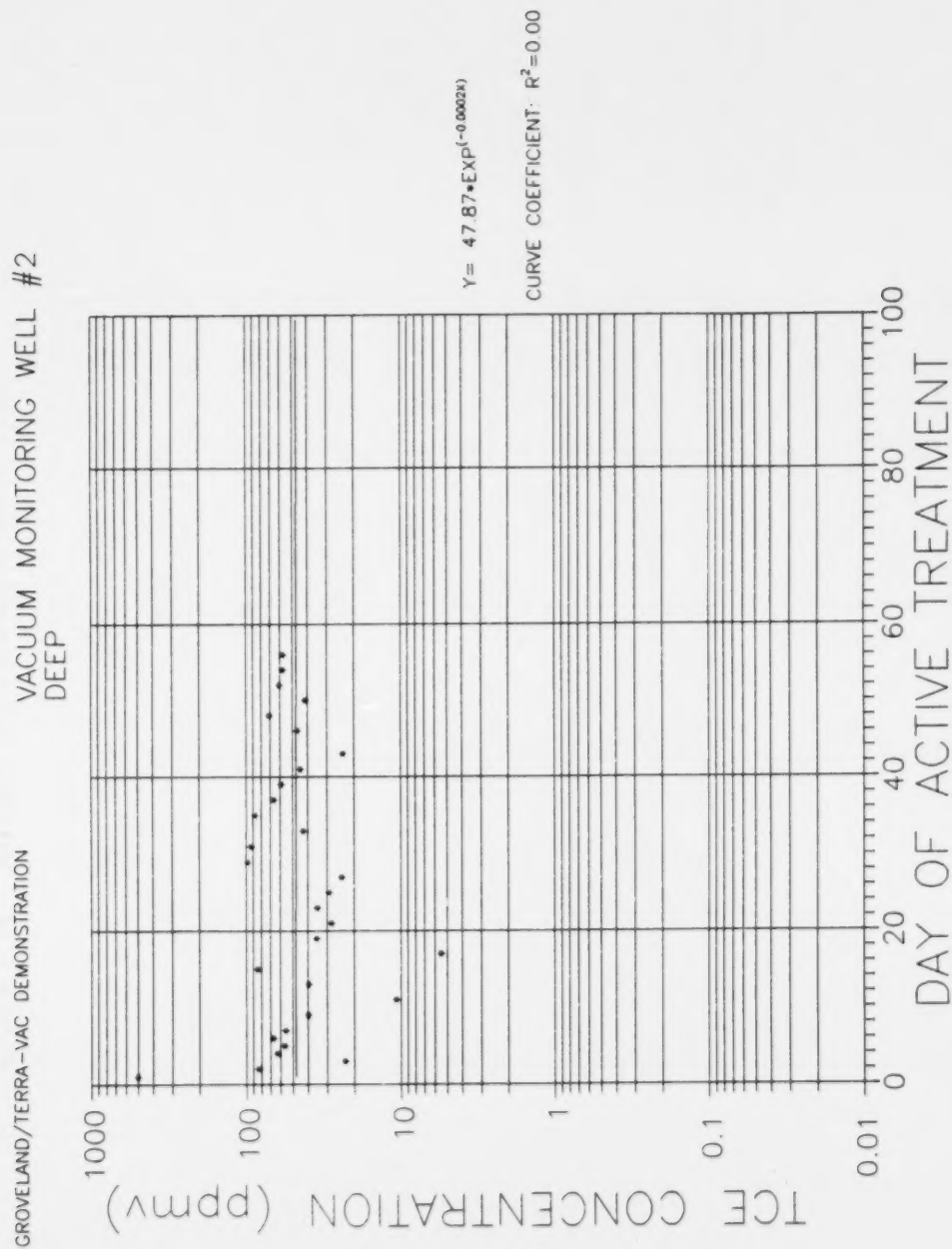


Figure 6.15. Wellhead TCE concentration vs time.

GROVELAND/TERRA-VAC DEMONSTRATION,

VACUUM MONITORING WELL #3
SHALLOW

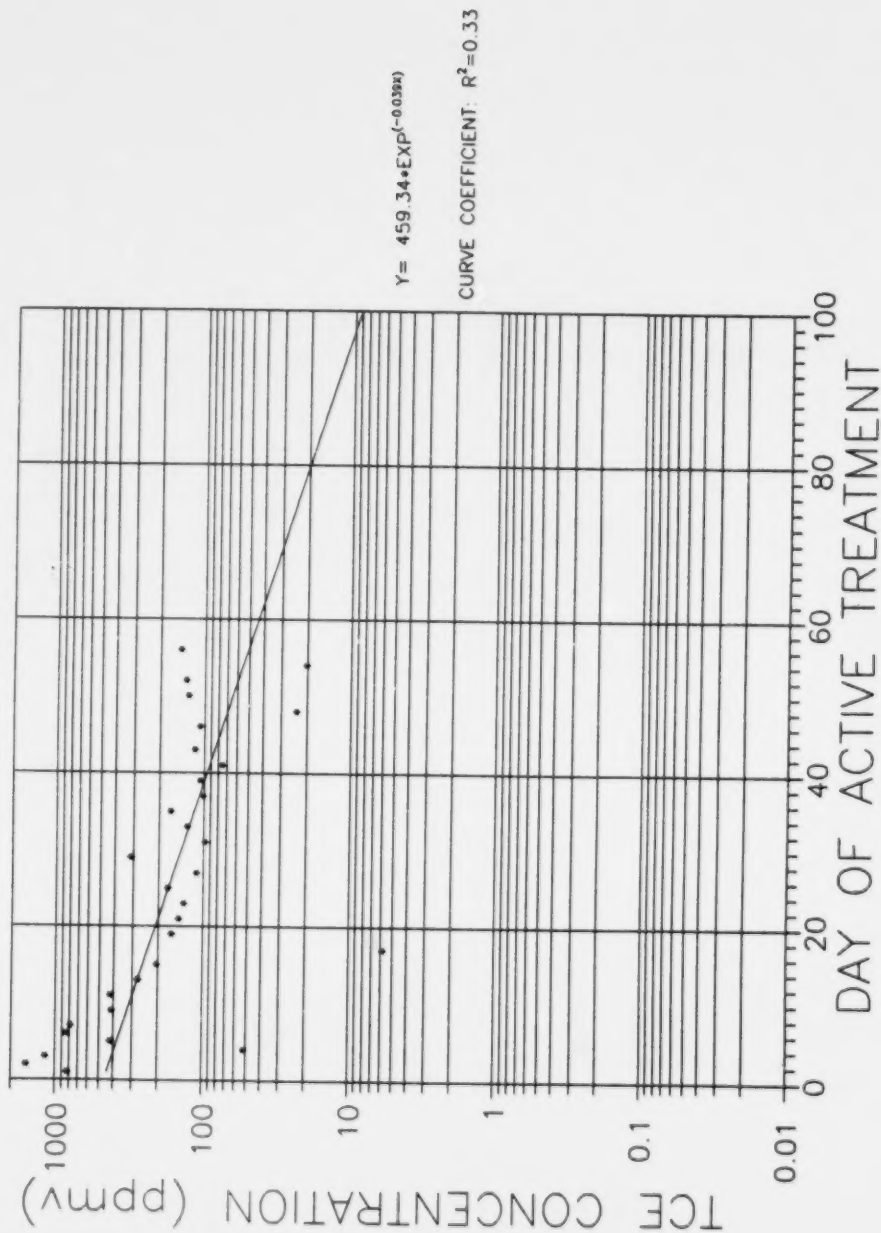


Figure 6.16. Wellhead TCE concentration vs time.

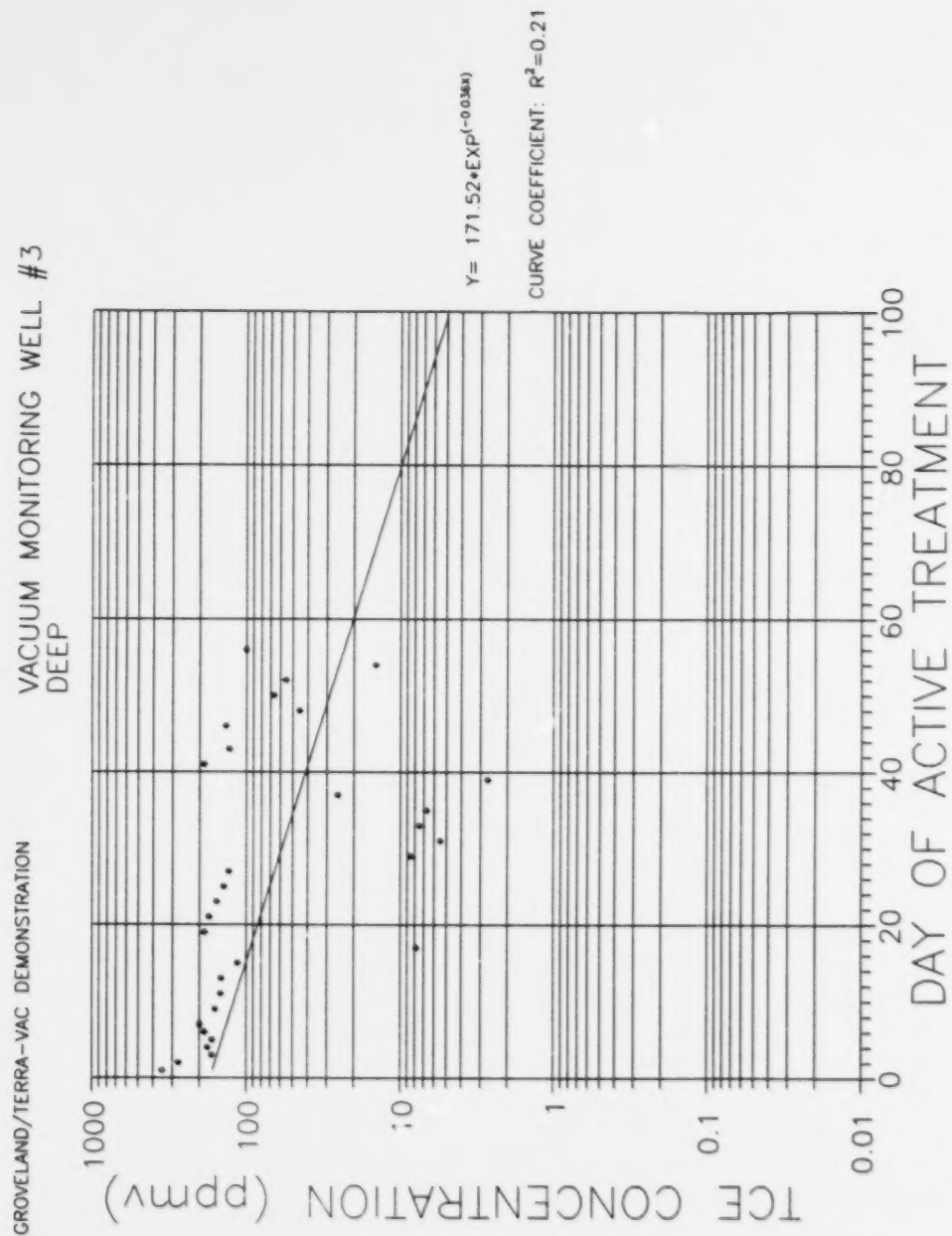


Figure 6.17. Wellhead TCE concentration vs time.

GROVELAND/TERRA-VAC DEMONSTRATION

VACUUM MONITORING WELL #4
SHALLOW

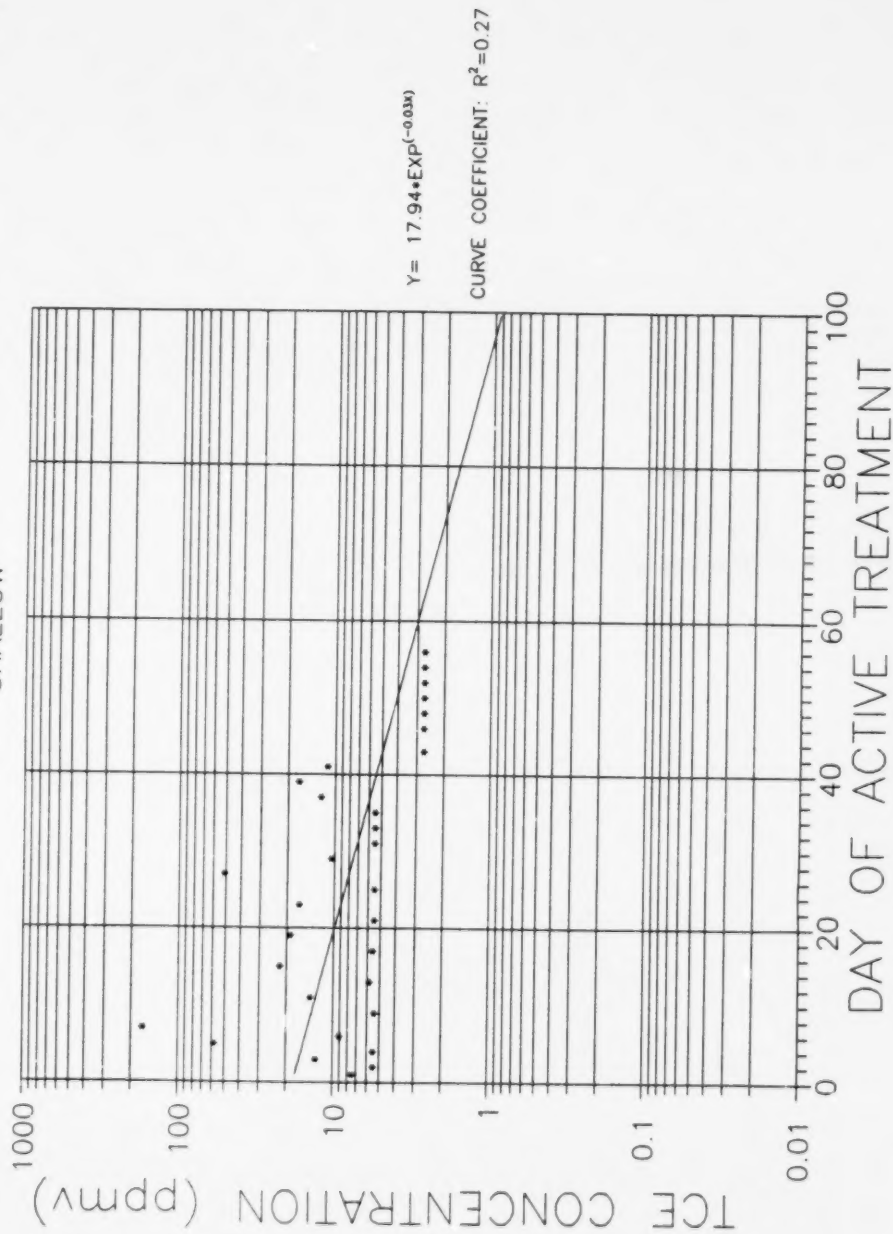


Figure 6.18. Wellhead TCE concentration vs time.

GROVELAND/TERRA-VAC DEMONSTRATION

VACUUM MONITORING WELL #4
DEEP

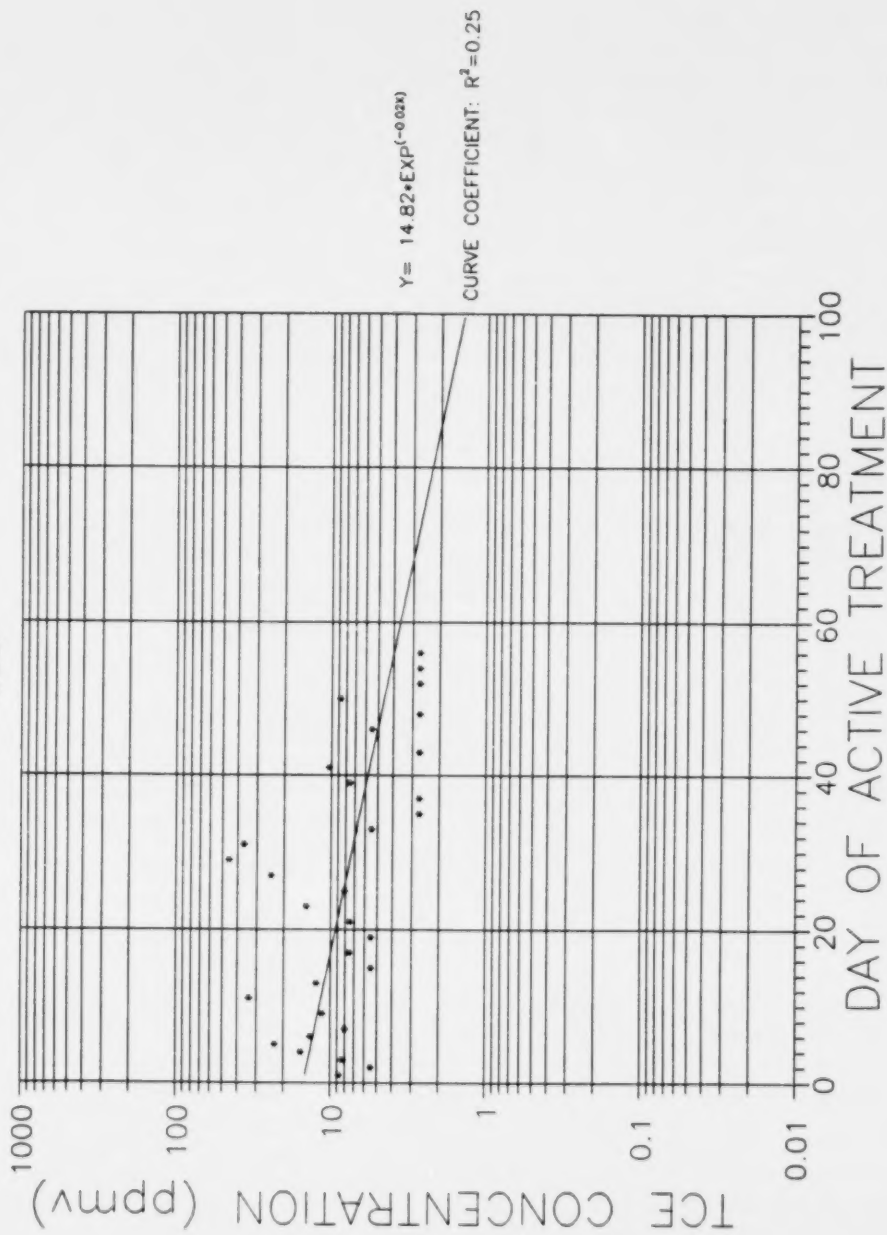


Figure 6.19. Wellhead TCE concentration vs time.

The maximum contaminant level goal (MCLG) for trichloroethylene in drinking water is zero. An achievable detection limit for TCE in water is 5 ppb and the regulatory limit is 3.2 ppb. It is this regulatory limit value that is used in the VHS model as the compliance point concentration to solve for a value of leachate concentration. This value of leachate concentration is then used in the Organic Leachate Model to solve for soil concentration.

The VHS model is expressed as the following equation:

$$C_y = C_0 \operatorname{erf} (Z/(2(a_z Y)^{0.5})) \operatorname{erf} (X/(a_t Y)^{0.5})$$

where:

- C_y = concentration of VOC at compliance point (mg/l)
- C_0 = concentration of VOC in leachate (mg/l)
- erf = error function (dimensionless)
- Z = penetration depth of leachate into the aquifer
- Y = distance from site to compliance point (m)
- X = length of site measured perpendicular to the direction of ground water flow (m)
- a_t = lateral transverse dispersivity (m)
- a_z = vertical dispersivity (m)

A simplified version of the VHS model is most often used, which reduces the above equation to:

$$C_y = C_0 C_f$$

where:

- C_f = $\operatorname{erf} (Z/(2(a_z Y)^{0.5})) \operatorname{erf} (X/(a_t Y)^{0.5})$, which is reduced to a conversion factor corresponding to the amount of contaminated soil

The Organic Leachate Model (OLM) is written as:

$$C_0 = 0.00211 C_s^{0.678} S^{0.373}$$

where:

- C_0 = concentration of VOC in leachate (mg/l)
- C_s = concentration of VOC in soil (mg/l)
- S = solubility of VOC in water (mg/l)

A concentration of 50 ppb TCE in the soil would correspond to a level of 8.9 ppb in the wellhead gas for EWS 1, and to a level of 38.9 ppb in the wellhead gas for EWD2. Extraction times of approximately 200 days for EWS1 and 180 days for EWD1 are obtained by solving the equations derived for the curves of log concentration vs. time (Figures 6.4 and 6.5). During the course of this demonstration project, it had been observed that after stoppages of the extraction process, there would be significant increases of wellhead gas

concentrations upon restart. Near the end of the projected remediation time, it should be possible to determine if the site has been decontaminated by running the vacuum blower intermittently and measuring the wellhead gas concentration. If there is no significant increase in concentration, then the process should be stopped.

SECTION 7

ECONOMICS

7.1 INTRODUCTION

The classical cost analysis addresses the cost aspects of a capital facility in two main categories: capital costs, and operating and maintenance costs.

Capital costs include both depreciable and nondepreciable cost elements. Depreciable costs include direct costs for site development, capital equipment, and equipment installation. Indirect costs include 1) engineering services prior to unit construction, such as feasibility studies and consultant costs; 2) administrative tasks, such as permitting; 3) construction overhead and fee; and 4) contingencies. Nondepreciable costs include costs for vendor personnel and operator training, trial or test run expenses, working capital, and land purchase, which is a direct cost that is nondepreciable.

Operating and maintenance costs include variable, semivariable, and fixed cost elements. Variable operating cost elements include utilities and residual/water disposal costs. Semivariable costs include unit labor and maintenance costs, and laboratory analyses. Fixed costs include depreciation, insurance, and taxes.

The above breakdown of cost elements, however, is based on a permanently sited vacuum extraction unit. The Terra Vac vacuum extraction unit as employed at the Groveland site is a transportable skid-mounted unit that will not be located permanently at a site. Cost analysis, therefore, is based on different sets of cost elements.

In general, the costs for a mobile vacuum extraction unit fall into three categories: 1) capital costs including all costs that can be amortized over the service life of the unit; 2) mobilization/demobilization costs associated with start-up and shutdown at a given site, which can be amortized while the unit is transported to and located and operated at a given site; and 3) costs of operating and maintaining the system.

Capital costs can be subdivided into direct, indirect, and nondepreciable cost elements; mobilization/demobilization costs can be accrued as semivariable operating and maintenance costs; and operating costs include variable utility, costs, semivariable labor or maintenance costs, and fixed costs such as depreciation, insurance, and taxes.

In addition, for a mobile unit, several capital cost elements defined for the permanently sited unit should be redefined into a different cost element category. These include the direct costs for site development and the direct costs for engineering studies, which now will be accrued on a site-specific basis and as such become mobilization/demobilization costs. They now fall under semivariable operating and maintenance costs.

Based on the above, an overall cost element breakdown, as illustrated in Table 7.1, can be developed.

Included in Section 7.3, Table 7.2 is an economic model for a current-case ideal Terra Vac transportable unit operation that is equivalent in processing capacity to the unit that operated at the Groveland site. It should be noted that cost data on the operations at Groveland are high due to the nature of the demonstration project.

7.2 COST ELEMENTS

A discussion of each of the cost elements defined in Table 7.1 is provided in the following:

7.2.1 Capital Costs

Direct Costs: Equipment Fabrication and Construction--

The current costs for the design, engineering, materials and equipment procurement, fabrication, and installation of the Terra Vac transportable vacuum extraction unit are included as direct costs. These costs include all the subsystems and components installed on their respective skids and trailers, but do not include the costs of the tractors for the transport of the trailers.

Indirect Costs: Contingency--

In any cost estimate, contingency costs approximating 10% of the direct capital cost is an acceptable factor; this allows for unforeseen or poorly defined cost definitions.

Nondepreciable Costs--

Operations procedures and training--In order to ensure the safe, economical, and efficient operation of the unit, operating procedures and a program to train operators are necessary. These associated costs will accrue: the preparation of a unit health and safety and operating manual; and the development and implementation of an operator training program, equipment decontamination procedures.

7.2.2 Operating and Maintenance Costs

Variable costs--

Variable operating cost elements for this unit include power and residue/water disposal. They are defined as variable operating cost elements because they can usually be expressed in terms of dollars per unit flow of waste disposed, and as such, these costs are more or less proportional to overall facility utilization during specific site operations.

TABLE 7.1. OVERALL COST ELEMENT BREAKDOWN

CAPITAL COST

Direct

- o Equipment Fabrication/Construction

Indirect

- o Contingency

Nondepreciable

- o Operations Procedures/Training

OPERATING AND MAINTENANCE COSTS

Variable

- o Power
- o Residue/Water Disposal
- o Activated Carbon

Semivariable

- o Labor
- o Maintenance
- o Analyses
- o Mobilization/Demobilization

- Site Preparation/Logistics
- Transportation/Setup
- On-Site Checkout
- Site-Specific Permitting/Engineering Services
- Working Capital
- Decontamination/Demobilization

Fixed

- o Depreciation
 - o Insurance
 - o Taxes
-
-

Power--The power requirements for the unit include the electrical requirements for the motors that power the pumps, fans, vacuum pump, and the small separator water pump. Auxiliary electrical requirements for power for the two field trailers, site lighting, etc., are minimal and are assumed to be included in the total power needs.

Activated carbon--Activated carbon requirements amounted to a usage of 15,200 lb over the course of the demonstration. The cost of the activated carbon includes the cost of regeneration.

Waste disposal--The waste disposal costs are the costs for disposing of the contaminated water collected in a fully permitted biological treatment facility. There were 17,000 gal of water disposed of during the course of the test.

Semivariable Costs--

Labor--Operating personnel for the Terra Vac unit was 1 person during the day shift. The main tasks for this operator consisted of taking daily gas samples and changing out carbon canisters.

Maintenance--Maintenance materials and labor costs are extremely difficult to estimate and cannot be predicted as functions of a few simple waste and facility design characteristics, because a myriad of site-specific factors can dramatically affect maintenance requirements.

Analyses--In order to ensure that the unit is operating efficiently and meeting environmental standards, a program for the intermittent analysis of wellhead gas and stack gas is required. These costs also include pretest and posttest soil sampling and analysis.

Mobilization/demobilization--As discussed in Section 7.1, the following costs will accrue to the Terra Vac unit at each specific site. The costs are site-specific and may vary somewhat depending on the nature and location of the site. They include site preparation and logistics, transportation and setup, construction supervision, on-site check-out, site-specific permitting and engineering services, working capital, and decontamination/demobilization.

- o Site preparation--Site preparation consisted of the setup and outfitting of a trailer, which was used as a base of operations; the provision of electrical service both for the trailer and for the vacuum pump skid and water pump; the minor grubbing and cleaning of the site; and installation of extraction and monitoring wells. The vacuum pump skid required the extension of an existing 440V, 3pH, 60hz line in the Valley Manufactured Products plant back to the demonstration area with the installation of a circuit breaker and electric power meter. The trailer power line was run from a street pole and a meter installed. Various outside lights and switches were installed to make the area more secure. The setup and equipping of the S&A trailer was not considered as a cost for this demonstration since it would not be a typical cost for this technology.

- o On-site check-out--Once the unit has been set up, it is necessary to shakedown the system to ensure that no damage occurred as a result of disassembly, transport, and reassembly.
- o Site closure--Site closure costs include the entire costs accrued on the project for hazardous waste disposal, and minor demobilization costs. Hazardous waste disposal required the retaining of a subcontractor specializing in the preparation for shipment and shipment of hazardous wastes. The hazardous wastes handled at the site included liquid waste, both bulk and in drums, which were either extracted by the vacuum system or collected as a result of decon procedures. This liquid waste was manifested and shipped to a biological treatment facility that was fully permitted and in full regulatory compliance. Solid waste consisted of contaminated soil tailings from drilling operations and was manifested and shipped to an incineration facility. Demobilization would normally include dismantling and closure of the extraction and monitoring well installation, but owing to future consideration this was not done at the completion of this project.

7.3 OVERALL COST EVALUATION

An economic model for an efficiently operated current-cost Terra Vac vacuum extraction unit operation equivalent in processing capacity to the unit that operated at Groveland is presented in Table 7.2. The model is based on vacuum extraction of the total volume of contaminated soil at the Valley site equal to 6,000 tons.

In actual operation, the Terra Vac unit was on site for approximately 147 days, 56 days of which was an actual demonstration test run. The costs in Table 7.2 are for this 56-day period during which contaminant levels were significantly reduced, but a complete remediation was not yet attained.

TABLE 7.2. ECONOMIC MODEL FOR TERRA VAC

<u>CAPITAL COST</u>	<u>\$/TON</u>
<u>Direct - Depreciable</u>	
Equipment Fabr./Constr.	(\$50,000)*
<u>Indirect - Depreciable</u>	
Contingency (10% Direct Cost)	0.83
<u>Indirect - Nondepreciable</u>	
Operations Proc./Training	0.40
<u>OPERATING AND MAINTENANCE COSTS</u>	
<u>Variable</u>	
Power (\$0.08/kwh)	0.40
Activated Carbon	12.83
Waste Disposal	7.50
<u>Semivariable</u>	
Labor	1.87
Living	0.90
Maintenance	0.28
Analyses	
- Pretest and Posttest soil	16.66
- Wellhead and Stack Gas During Operation	1.44
Mobilization/Demobilization	
Site Prep.	2.83
Transp./Setup &	
On-site Checkout	0.84
Decon./Demobil.	0.33
<u>Fixed</u>	
Depreciation (10 yrs. St. Line)	0.28
Insurance & Taxes (10% Direct Cost)	<u>0.28</u>
TOTAL COST PER TON	47.12

* Not used directly, but is used for the estimate of other costs.

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